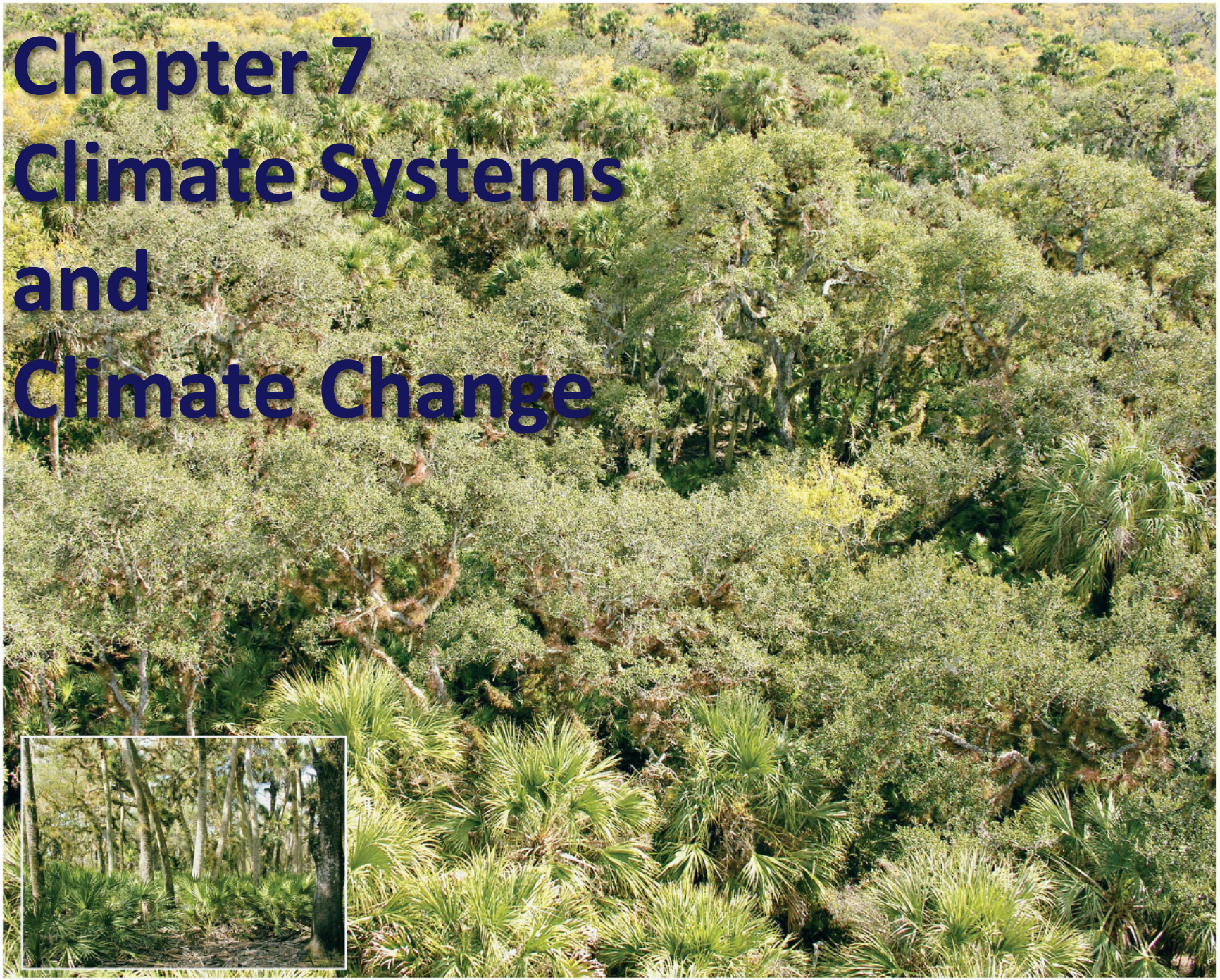
Chapter 7
Climate Systems and Climate Change



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Climate Systems and Climate Change

- **Earth's Climate System and Its Classification**
- **Tropical Climates**
- **Mesothermal Climates**
- **Microthermal Climates**
- **Polar and Highland Climates**
- **Arid and Semiarid Climates**
- **Global Climate Change**

Earth's Climate System and Its Classification

- Climate Components: Insolation, Temperature, Air Pressure, Air Masses, and Precipitation
- Classification of Climatic Regions
  - Global climate patterns

Earth's Climate System

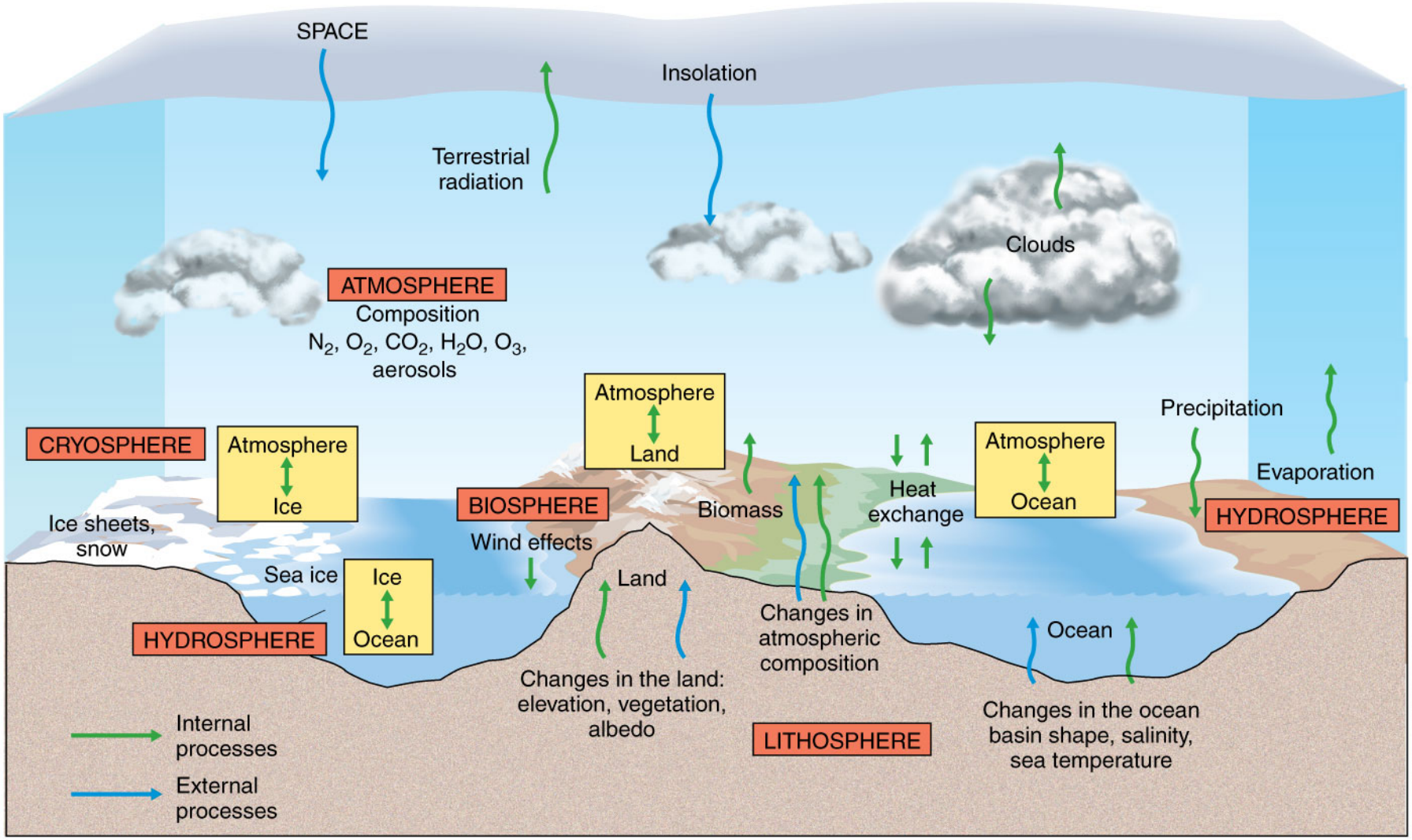

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Figure 7.1

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Worldwide Average Precipitation

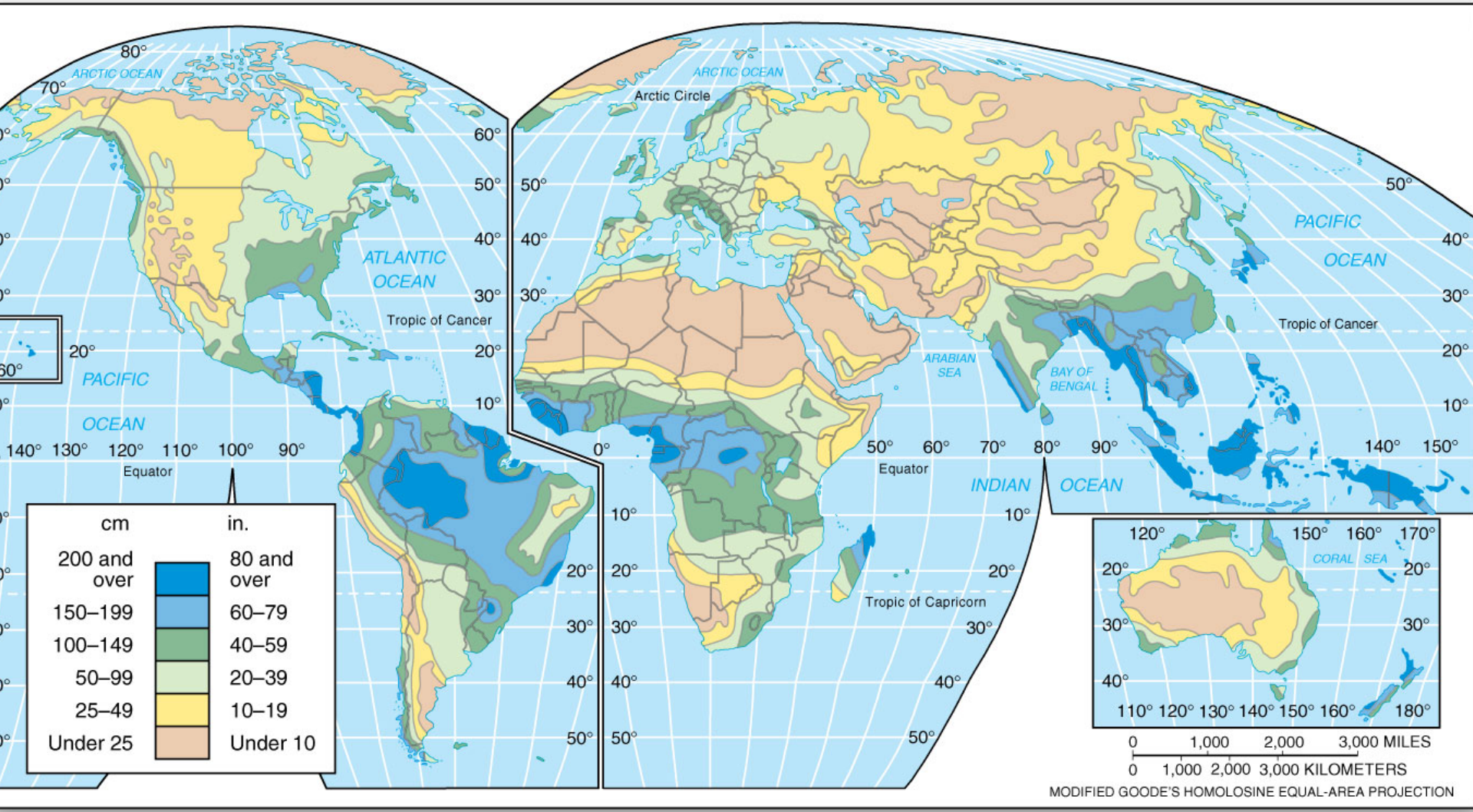

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Figure 7.2

Climatic Relationships

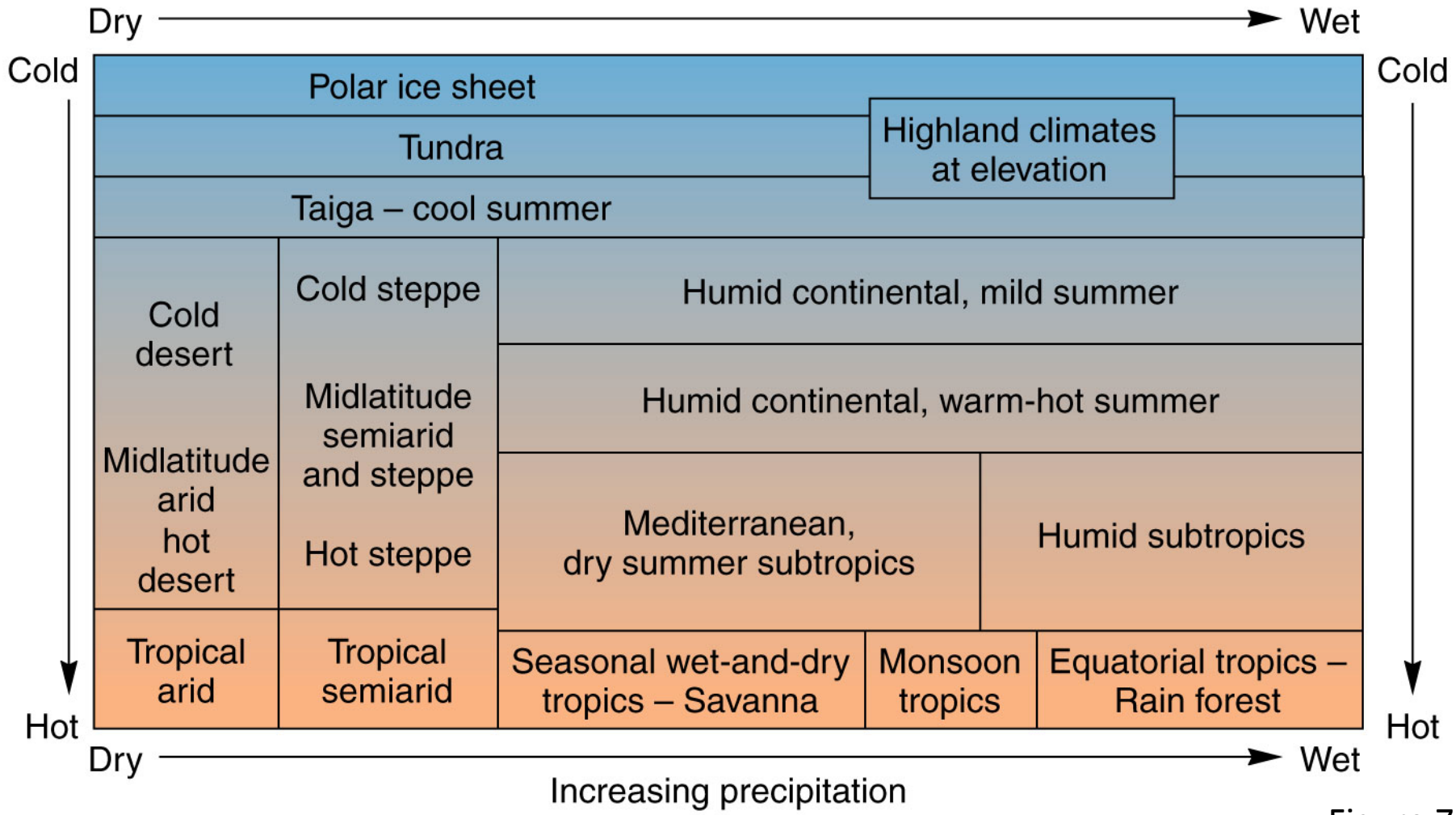

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Figure 7.3

EL NINO

- El Nino and the Southern oscillation – the Southern Oscillation is movement south of the ITCZ which is farthest south around Christmas each year
- Change in Ocean currents pattern
- Warm water slide over cold Peru current causing fluctuations in weather which are felt in Australia, US, Canada & elsewhere
- During El Nino years Lethbridge's weather is unseasonably warm & sunny; California experiences very heavy rain
- El Nino usually occurs 3 – 5 years; while La Nina (Peru current usually colder) sometimes occur between them

El Niño and La Niña

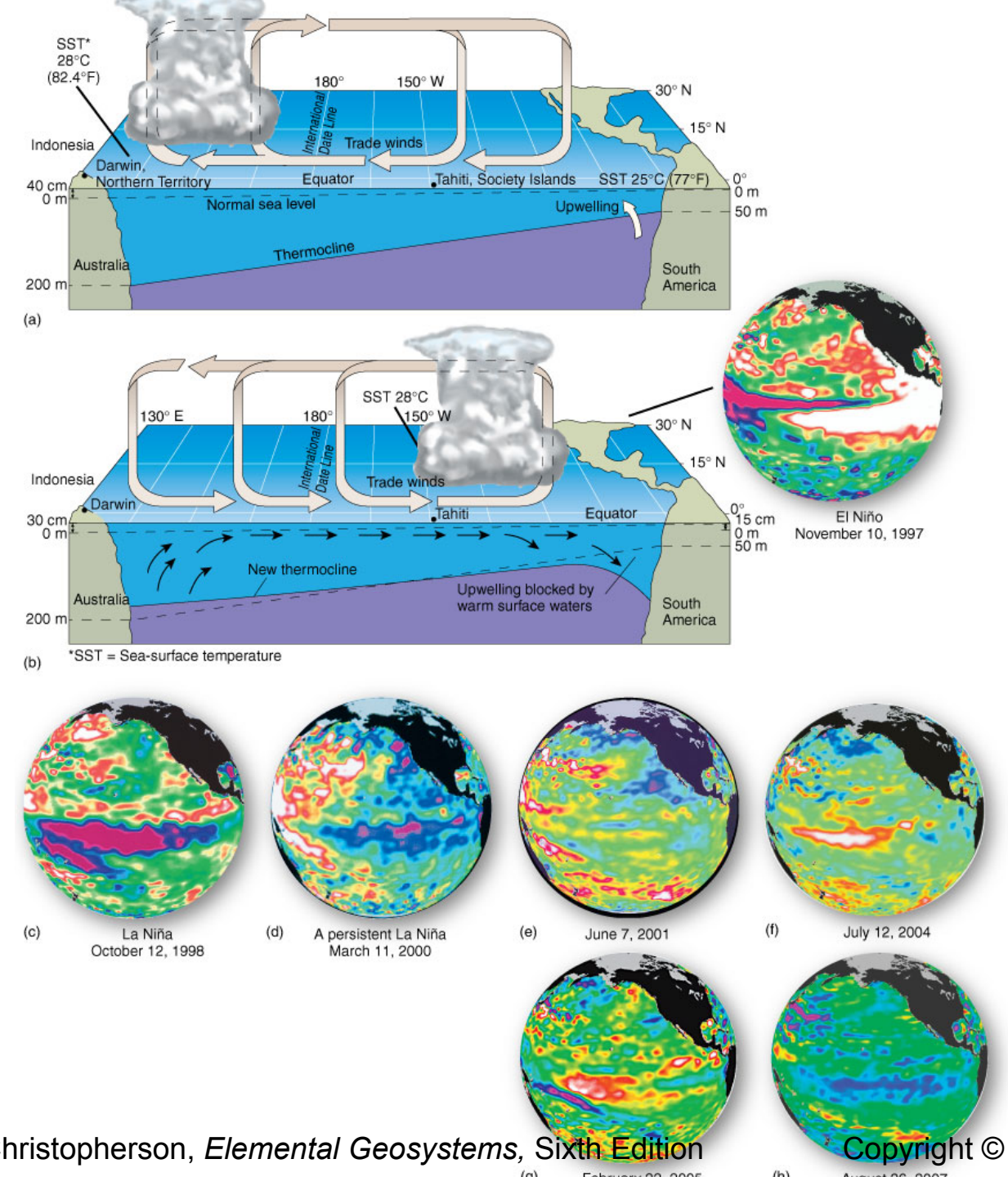

Figure FS 7.1.2

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Köppen's System of Climate Classification

- Köppen's Climate Classification System
  - Most widely used system for classifying the world's climate
  - It's categories based on the annual and monthly averages of
    - Temperature
    - Precipitation
  - Köppen's system recognizes 5 major climactic types including Highland climate
    - Each type is designated by a capital letter

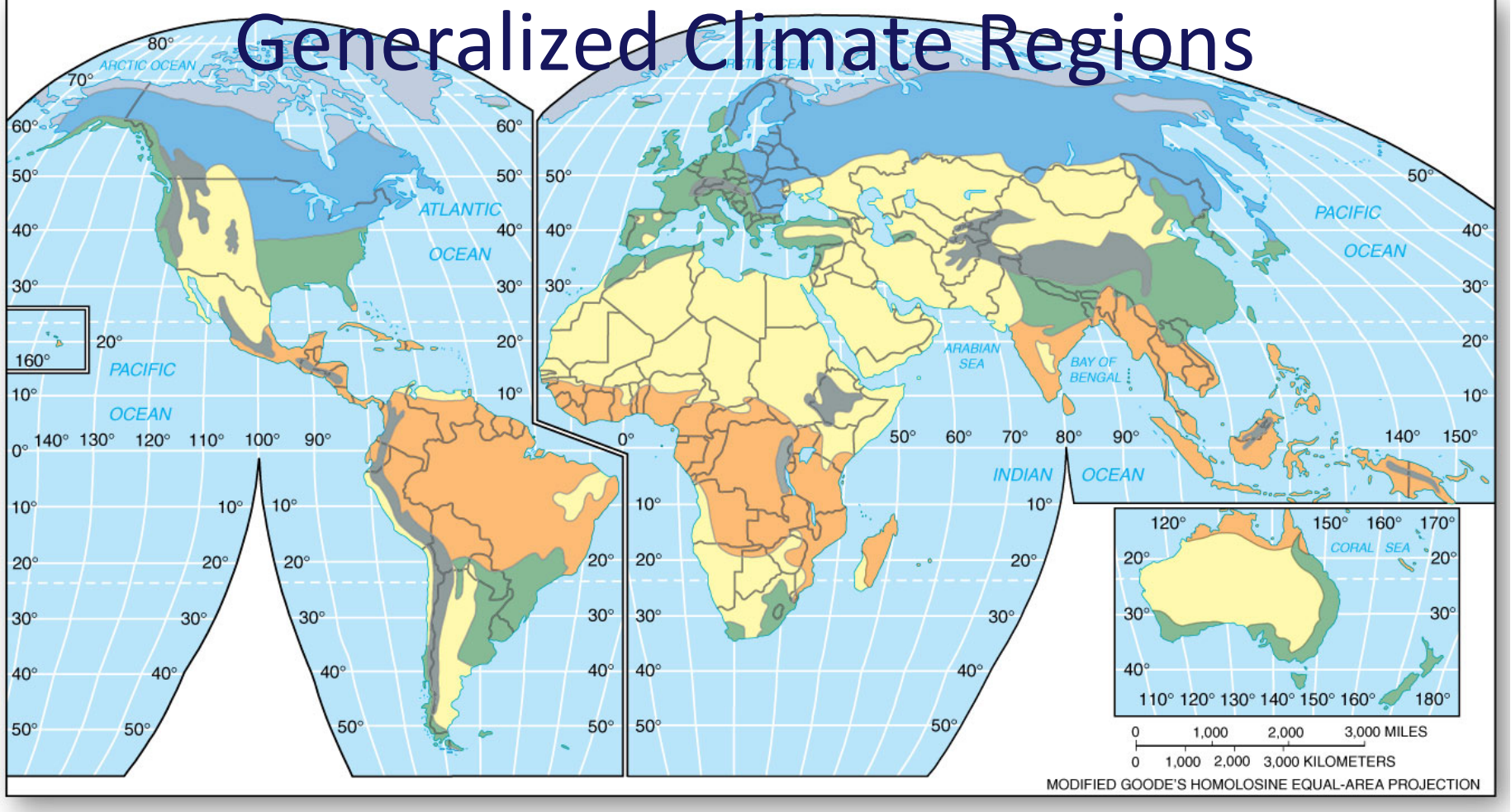
Köppen's System of Climate Classification

- A - Tropical Moist Climates
  - All months have average temperatures above 18°C
- B – Dry Climates
  - With deficient precipitation during most of the year
- C – Moist Mid-Latitude Climates with Mild Winters (Mesothermal)
- D – Moist Mid-Latitude Climates with Cold Winters (Microthermal)
- E – Polar Climates
  - With extremely cold winters and summers
- H - based on elevation (Highlands)
  - Cold climates due to elevation

Köppen's System of Climate Classification

- A – moist, tropical
    - Af – Tropical rain forest
    - Am – Tropical monsoon
    - Aw – Tropical Wet & Dry - savanna
- B – dry
    - Arid desert
    - Semi-arid desert
- C – moist
    - Humid subtropical
    - Mediterranean
    - Marine
- D – moist
    - Dry winters
    - Dry summers
    - Wet all year seasons
- E – Polar
    - Polar tundra
    - Polar ice caps

Generalized Climate Regions



Tropical climates (equatorial and tropical) — Rain forest, Monsoon, Savanna

Mesothermal (mild winter) — Humid subtropical, Marine west coast, Mediterranean

Microthermal (cold winter) — Humid continental, Subarctic

Polar — Tundra, Ice caps and ice sheets

Desert — Arid deserts, Semiarid steppes

Highland (elevation effects)

Figure 7.4

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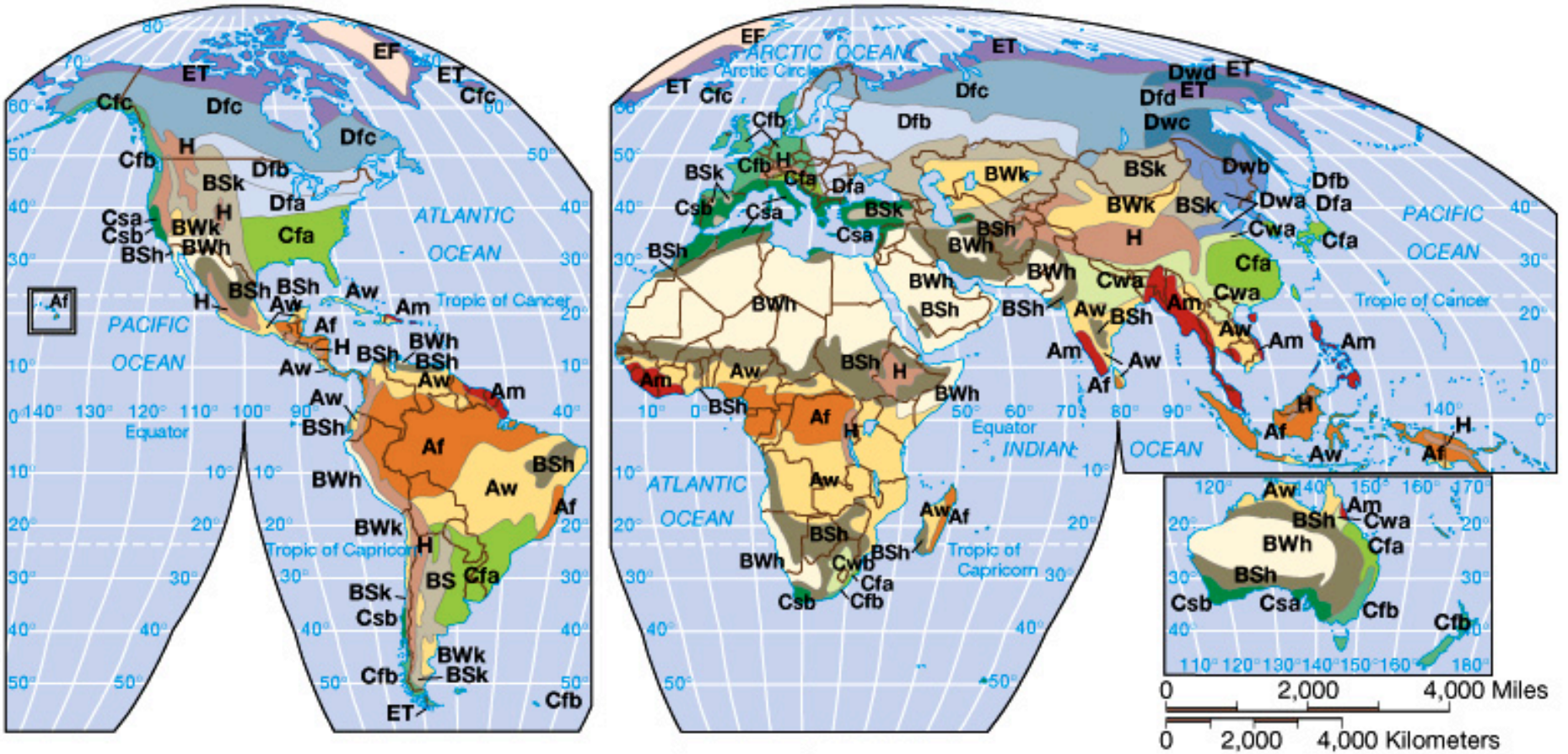


A TROPICAL HUMID CLIMATES

- **Af** Tropical wet climate
- **Am** Tropical monsoonal climate
- **Aw** Tropical savanna climate

B DRY CLIMATES

- **BWh** Subtropical desert
- **BWk** Midlatitude desert
- **BSh** Subtropical steppe
- **BSk** Midlatitude steppe

C MILD MIDLATITUDE CLIMATES

- **Cfa** Humid subtropical, no dry season
- **Cwa Cwb** Humid subtropical, winter-dry
- **Cfb Cfc** Marine west coast, no dry season
- **Csa Csb** Mediterranean summer-dry

D SEVERE MIDLATITUDE CLIMATES

- **Dfa Dfb** Humid continental, no dry season
- **Dwa Dwb** Humid continental, winter–dry
- **Dfc Dfd** Subarctic, no dry season
- **Dwc Dwd** Subarctic, winter–dry

E POLAR CLIMATES

- **ET** Tundra
- **EF** Ice cap

H HIGHLAND

- **H** Cold climates due to elevation

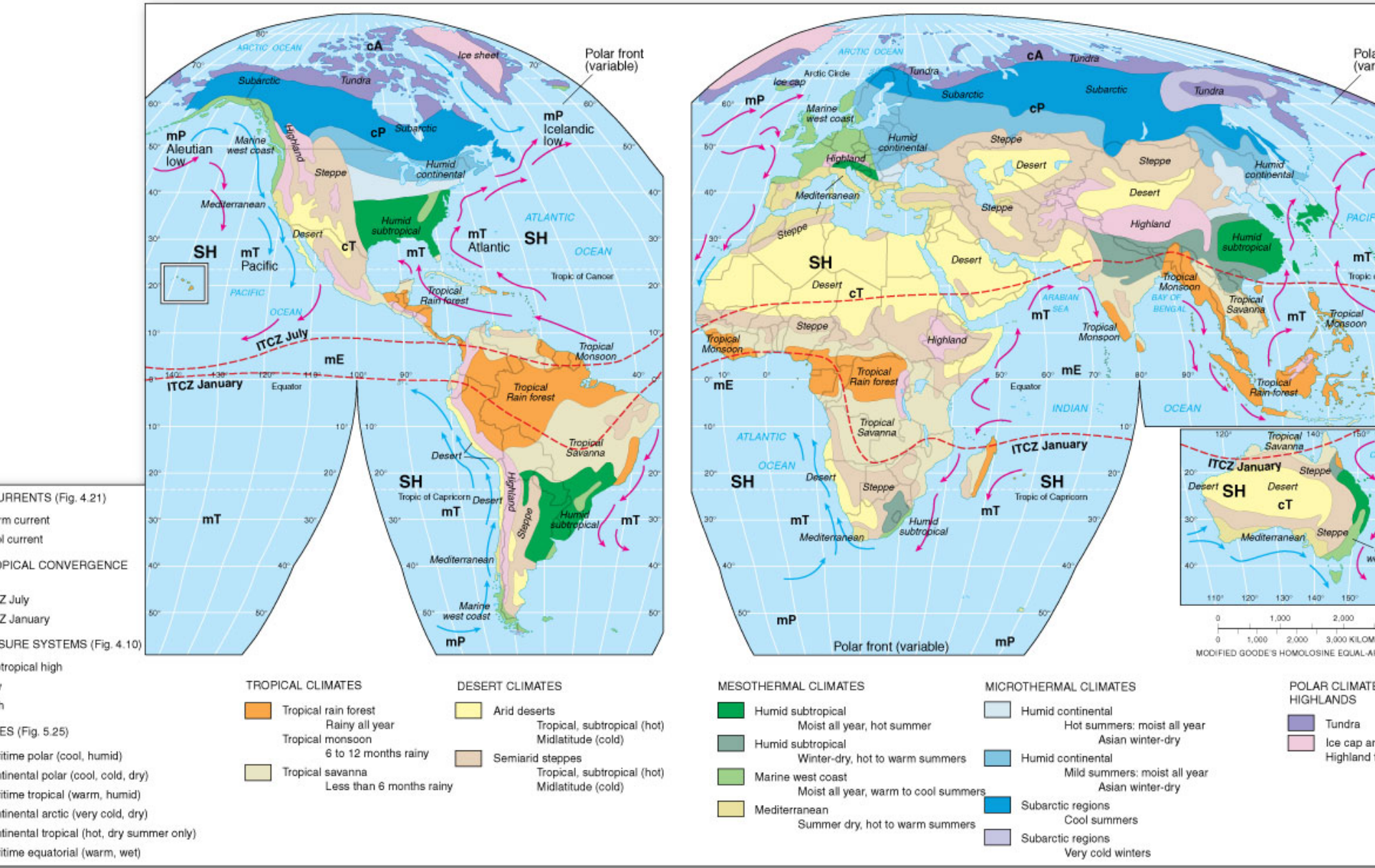
Köppen's Classification System

- *Tropical Moist Climates (A)*
  - (equatorial and tropical latitudes): most extensive; occupies about 36% of earth's surface; straddles the equator from about 20°N to 20°S latitude
  - Consistent day-length & insolation input
    - Temp – avg. > 18°C
    - Precipitation - > 1500 mm
  - located in the ITCZ (10 -15 N/S)
  - Evapotranspiration occurs at potential rate
  - warm ocean temperatures & unstable maritime airmasses occur in this region

Tropical Climates

- *3 minor climate types based on seasonal distribution of rainfall*
- Tropical Rain Forest Climates
  - Precipitation occurs all year long
  - Cumulus and cumulonimbus clouds form early in the afternoon almost every day
  - Daily highs are above 32°C
  - Night time temperatures average 22°C
- Tropical Monsoon Climates
  - 6 to 12 months precipitation
  - During the dry season - little rainfall occurs
- Tropical Savanna Climates
  - Less than 6 months rainy
  - Has extended dry season during the winter
  - Precipitation during the wet season is less than 1000 mm and only during the summer season

World Climate Classification



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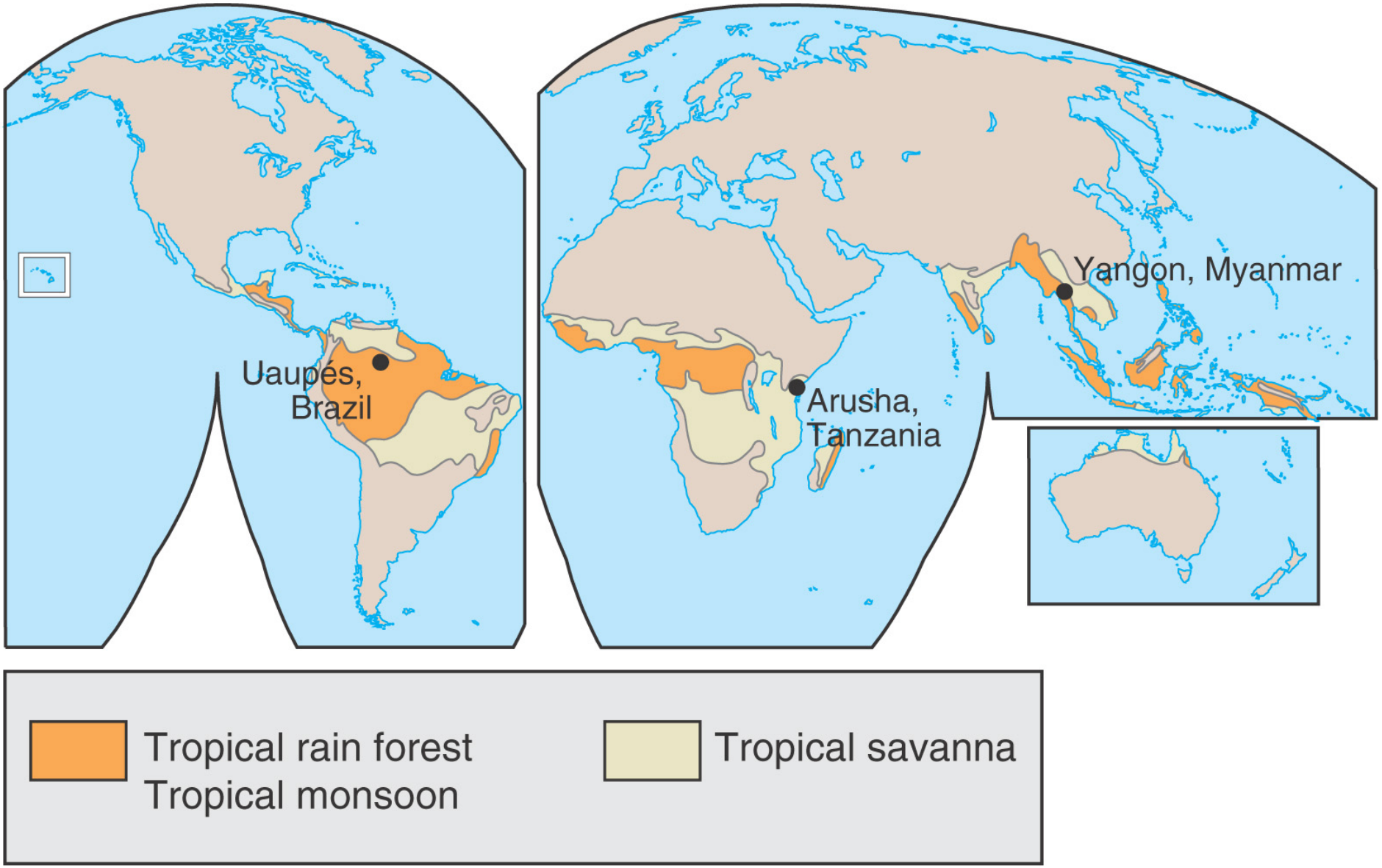
Tropical Climates



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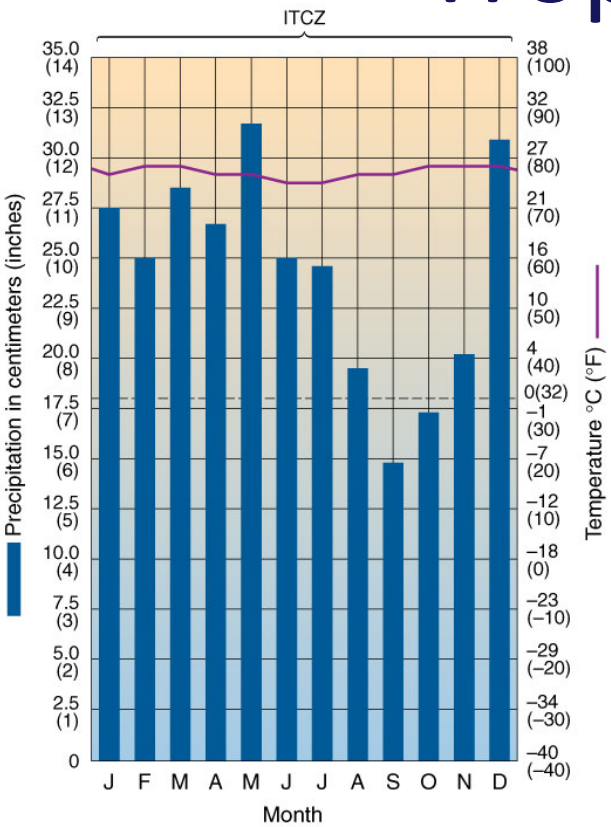
Tropical Rain Forest



Station: Uaupés, Brazil
Lat/long: 0°08′ S 67°05′ W
Avg. Ann. Temp.: 25°C (77°F)
Total Ann. Precip.:
291.7 cm (114.8 in.)
Elevation: 86 m (282.2 ft)
Population: 10,000
Ann. Temp. Range:
2 C° (3.6 F°)
Ann. Hr of Sunshine: 2018

(a)

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(b)

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Figure 7.6

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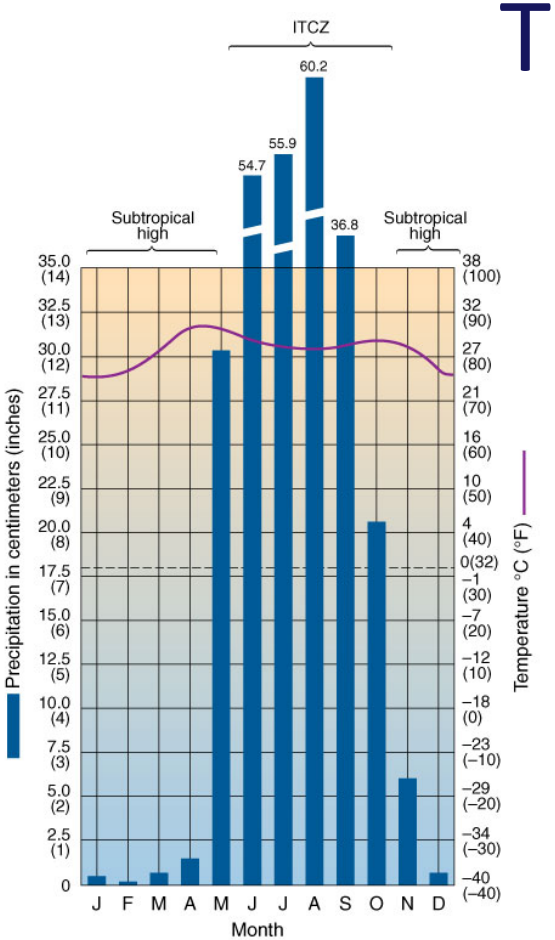
Tropical Monsoon



(a)

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Station: Yangon, Myanmar*
Lat/long: 16°47′ N 96°10′ E
Avg. Ann. Temp.: 27.3°C (81.1°F)
Total Ann. Precip.: 268.8 cm (105.8 in.)
Elevation: 23 m (76 ft)
Population: 6,000,000
Ann. Temp. Range: 5.5 C° (9.9 F°)

*(Formerly Rangoon, Burma)

(b)

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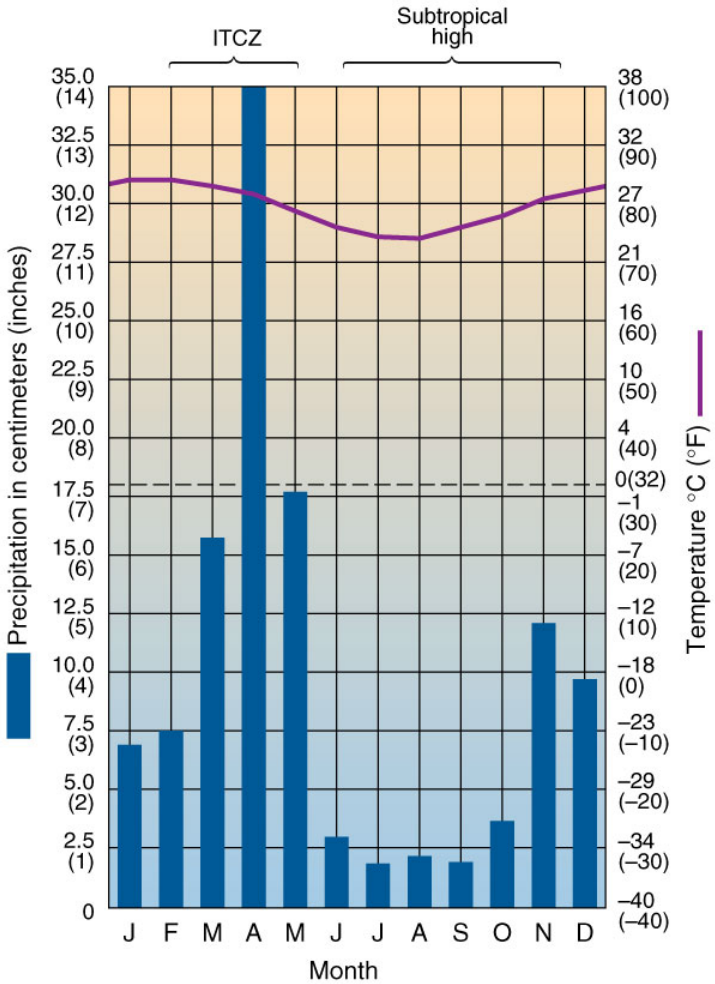
Tropical Savanna



Station: Arusha, Tanzania
Lat/long: 3°24′ S 36°42′ E
Avg. Ann. Temp.: 26.5°C (79.7°F)
Total Ann. Precip.: 119 cm (46.9 in.)

Elevation: 1387 m (4550 ft)
Population: 1,368,000
Ann. Temp. Range: 4.1 C° (7.4 F°)
Ann. Hr of Sunshine: 2600

(a)

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(b)

Figure 7.8

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Köppen's Classification System

- *Moist subtropical Midlatitude Climates (C)*
- Mesothermal climates (midlatitudes, mild winters)
  - > half the world's population (~ 55%) resides in these climates
  - Warm and humid summers with mild winters
  - Extends 30° – 50° latitude mainly on the eastern & western borders of most continents
    - Winter – mid-latitude cyclone
    - Summer - convective thunderstorms dominate
- Region of great weather variability
- Latitudes of greatest air mass interaction

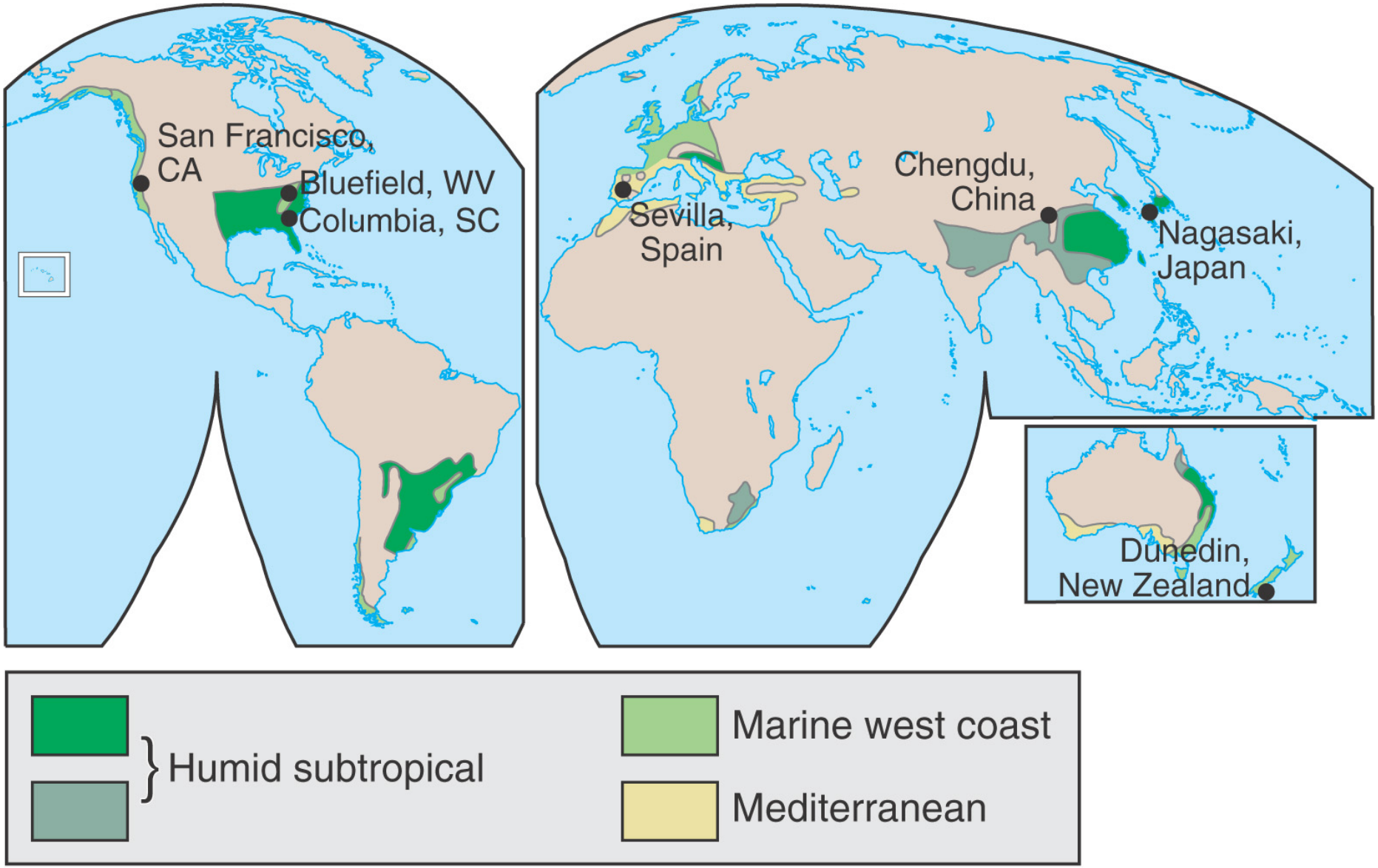
Köppen's Classification System

- Causal elements:
  - Shifting air masses of maritime & continental
  - Migrating cyclonic (low-pressure) and anti-cyclonic (high-pressure) systems
  - Sea-surface temperatures influence air mass strength; cooler along west coasts and warmer along east coasts
  - Climates are humid, except where subtropical high pressure produces dry-summer conditions

Mesothermal Climates

- *3 minor climate types exist:*
- Humid Subtropical Hot-Summer Climates
  - Maritime tropical air masses generated over warm waters influence these climates
- Marine West Coast Climates e.g. Vancouver
  - Western coasts of continents
  - Mild winters and cool summers
  - Maritime polar air masses; polar fronts
  - Humid climate; short dry summer
- Mediterranean Dry-Summer Climates
  - Shifting subtropical high-pressure cells block moisture bearing winds – extreme summer aridity
  - Shifting of stable, warm – hot, dry air over an area in summer and away from the regions in winter creates dry summers and wet winters

Mesothermal Climates



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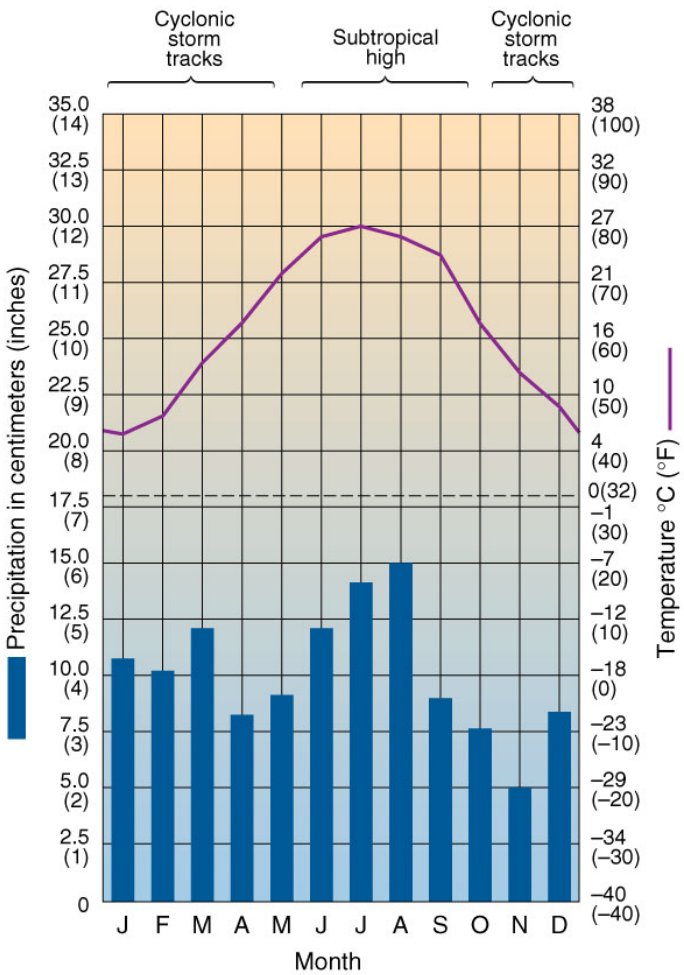
Humid Subtropical Hot-Summer



Station: Columbia, South Carolina
Lat/long: 34° N 81′ W
Avg. Ann. Temp.: 17.3°C (63.1°F)
Total Ann. Precip.: 126.5 cm (49.8 in.)

Elevation: 96 m (315 ft)
Population: 116,000
Ann. Temp. Range: 20.7 C° (37.3 F°)
Ann. Hr of Sunshine: 2800

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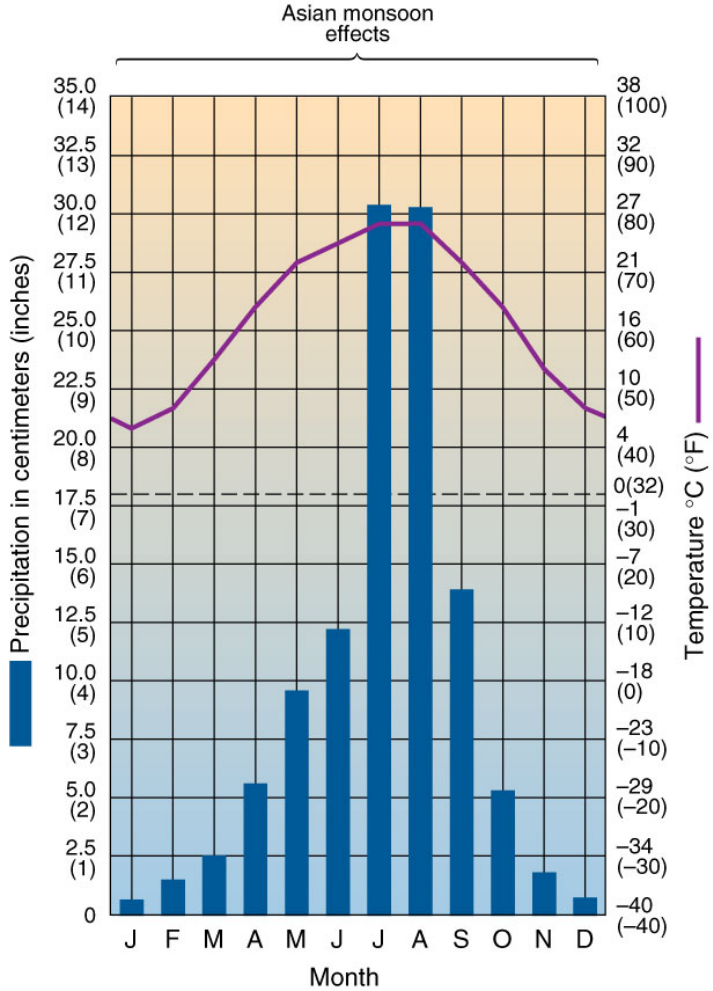
Humid Subtropical Winter-Dry



Station: Chengdu, China
Lat/long: 30°40′ N 104°04′ E
Avg. Ann. Temp.: 17°C (62.6°F)
Total Ann. Precip.: 114.6 cm (45.1 in.)

Elevation: 498 m (1633.9 ft)
Population: 2,500,000
Ann. Temp. Range: 20 C° (36 F°)
Ann. Hr of Sunshine: 1058

(a)

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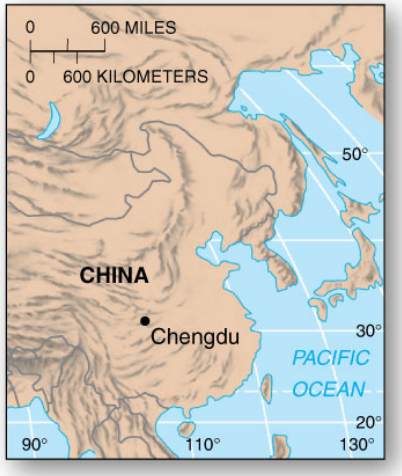
(b)



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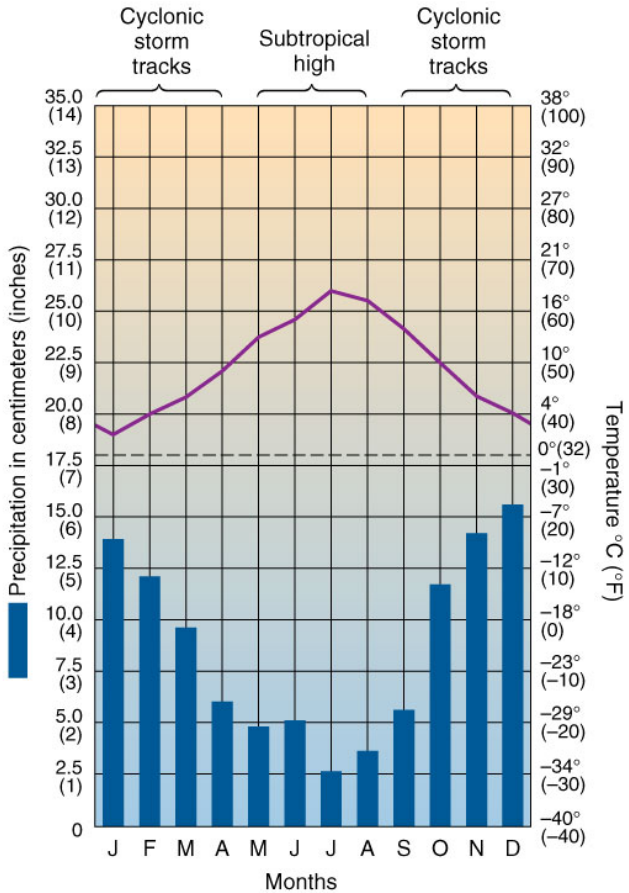
Marine West Coast



(a)

Station:
Vancouver, British Columbia
Lat/long: 49°11′ N, 123°10′ W
Avg. Ann. Temp.:
10° C (50° F)
Total Annual Precipitation:
104.8 cm (41.3 in.)
Elevation: sea level
Population: 1,580,000
Ann. Temp. Range:
16 C° (28.8 F°)
Ann. Hrs. of Sunshine:
1723

(b)

(c)

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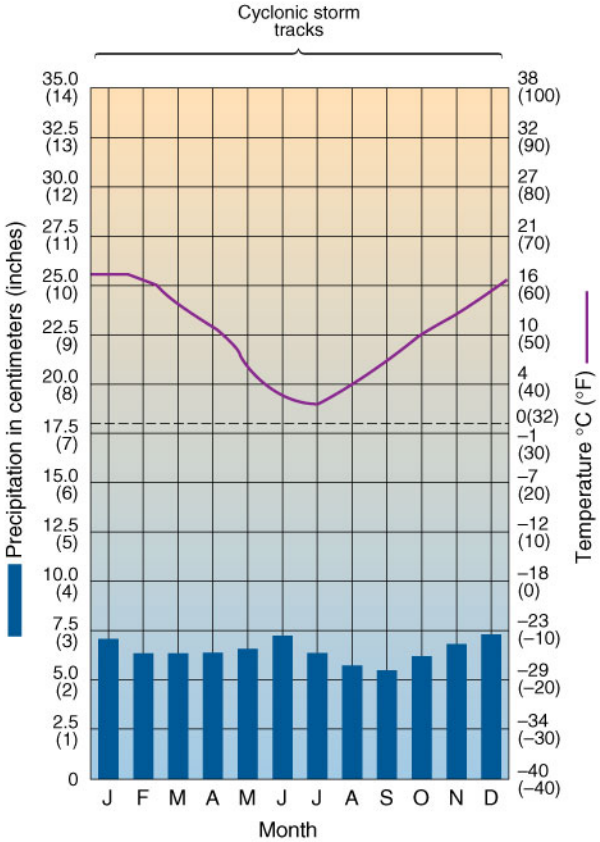
Marine West Coast



Station: Dunedin, New Zealand
Lat/long: 45°54′ S 170°31′ E
Avg. Ann. Temp.: 10.2°C (50.3°F)
Total Ann. Precip.: 78.7 cm (31.0 in.)

Elevation: 1.5 m (5 ft)
Population: 120,000
Ann. Temp. Range: 14.2 C° (25.5 F°)

(a)

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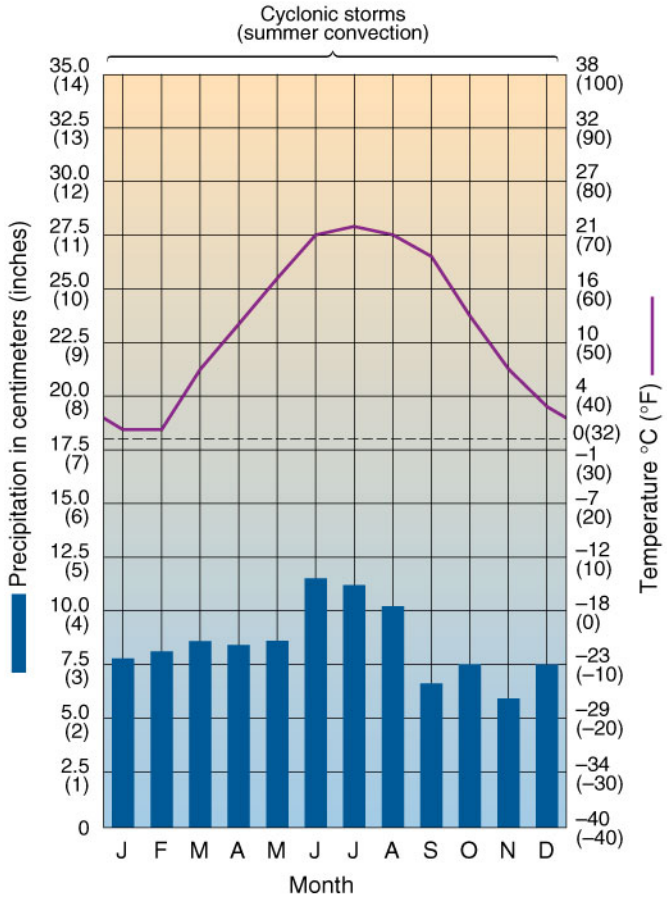
Marine West Coast



Station: Bluefield, West Virginia
Lat/long: 37°16′ N 81°13′ W
Avg. Ann. Temp.:
12°C (53.6°F)
Total Ann. Precip.:
101.9 cm (40.1 in.)
Elevation: 780 m (2559 ft)
Population: 11,000
Ann. Temp. Range:
21 C° (37.8 F°)

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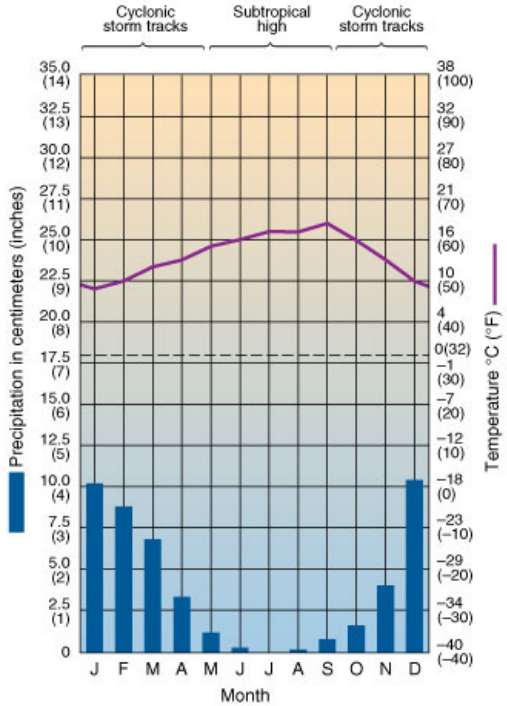
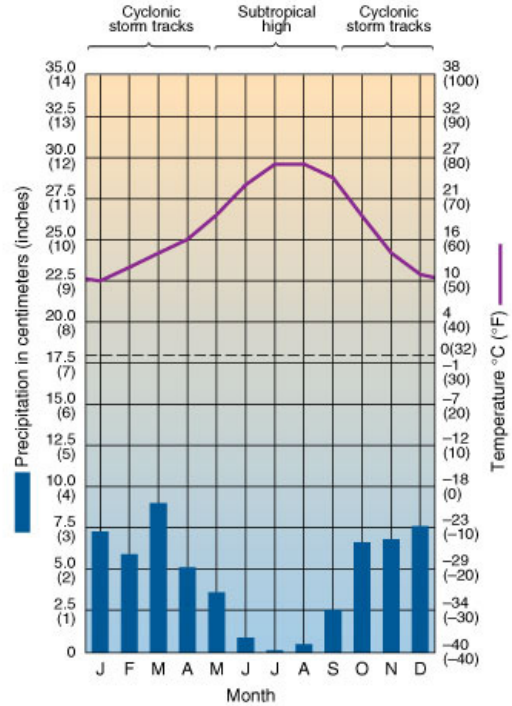
Mediterranean Climates



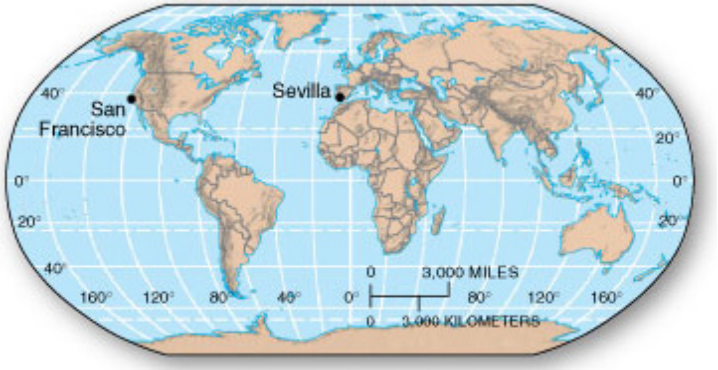
Station: San Francisco, California
Lat/long: 37°37′ N 122°23′ W
Avg. Ann. Temp.: 14°C (57.2°F)
Total Ann. Precip.: 47.5 cm (18.7 in.)
Elevation: 5 m (16.4 ft)
Population: 747,000
Ann. Temp. Range: 9 C° (16.2 F°)
Ann. Hr of Sunshine: 2975

(a)



Station: Sevilla, Spain
Lat/long: 37°22′ N 6°00′ W
Avg. Ann. Temp.: 18°C (64.4°F)
Total Ann. Precip.: 55.9 cm (22 in.)
Elevation: 13 m (42.6 ft)
Population: 1,764,000
Ann. Temp. Range: 16 C° (28.8 F°)
Ann. Hr of Sunshine: 2862

(b)



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(d)

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Köppen's Classification System

- *Moist Continental Mid-Latitude Climates (D)*
- Microthermal Climates (mid- and high- latitude, cold winter)
  - Humid microthermal climates have cold winters cool summers
    - Winters are severe with snowstorms, strong winds and bitter cold from Continental Polar or arctic air masses
  - ~21% of earth's land surface is influenced by these climates (7% of earth's total surface)
  - Occurs poleward of the mesothermal climates (C)
  - Experience great temperature ranges related to continentality and air mass conflicts

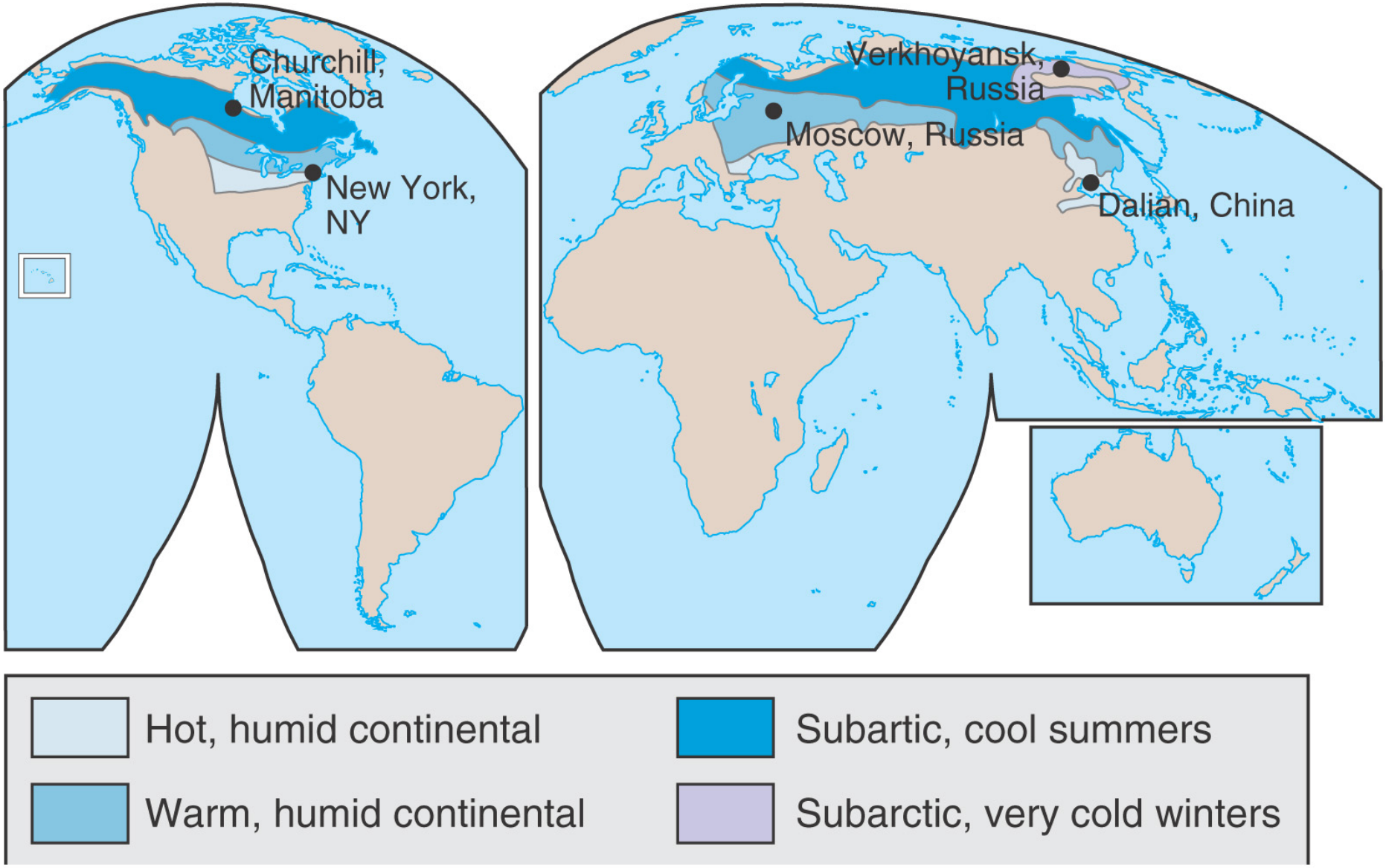
Köppen's Classification System

- Causal elements
  - Increasing seasonality
  - Upper air westerly winds bring warmer air northward and colder air southward
  - Convectional thunderstorms from mT masses in summer
  - Asian winter-dry pattern for microthermal climates
  - Hot summers cooling northward from the mesothermal climates; short spring and fall seasons surrounding winters that are cold to very cold
  - Continental regions – source regions for intense continental polar air masses (cP) that dominate winters

Microthermal Climates

- *3 minor climate types exist:*
- Humid Continental Hot-Summer Climates
  - In summer maritime tropical air masses influence both humid continental moist-all-year and winter-dry climates
- Humid Continental Mild-Summer Climates
  - Frost-free periods range from fewer than 90 days in the north to as many as 225 days in the south
- Subarctic Climates
  - Farther poleward, seasonal change becomes greater
  - Vast stretches of Alaska, Canada, northern Scandinavian – cool summers; Siberian, Russia with its very cold winters

Microthermal Climates



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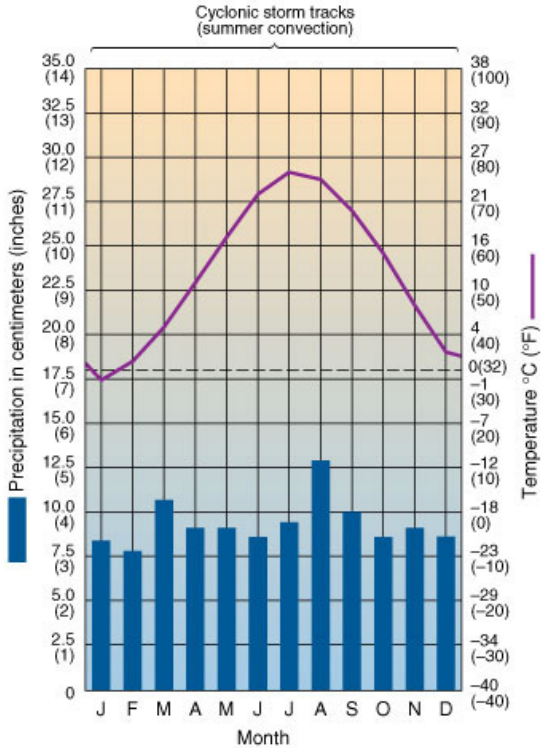
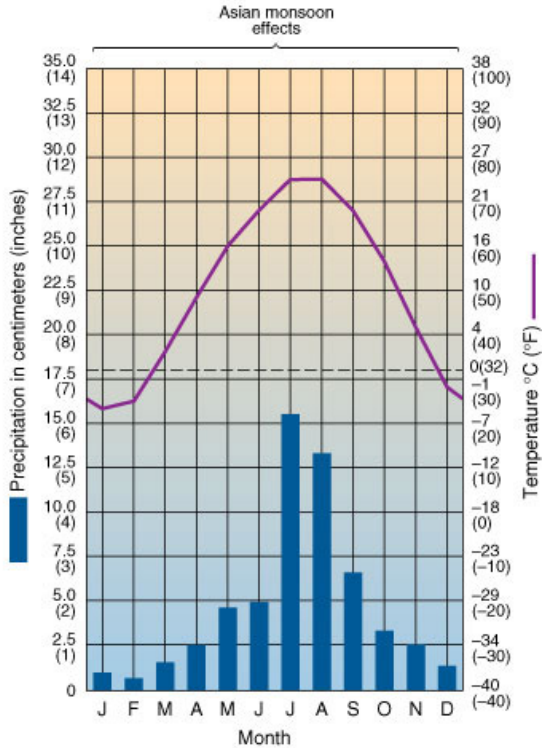
Humid Continental Hot-Summer Climates



Station: New York, New York
Lat/long: 40°46′ N 74°01′ W
Avg. Ann. Temp.: 13°C (55.4°F)
Total Ann. Precip.: 112.3 cm (44.2 in.)
Elevation: 16 m (52.5 ft)
Population: 8,092,000
Ann. Temp. Range: 24 C° (43.2 F°)
Ann. Hr of Sunshine: 2564

(a)

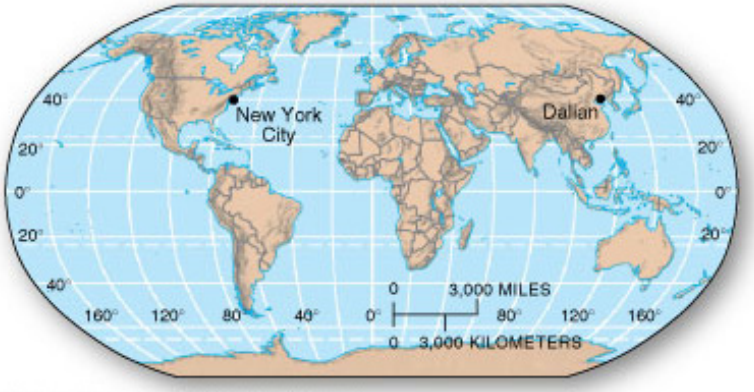


Station: Dalian, China
Lat/long: 38°54′ N 121°54′ E
Avg. Ann. Temp.: 10°C (50°F)
Total Ann. Precip.: 57.8 cm (22.8 in.)
Elevation: 96 m (314.9 ft)
Population: 5,550,000
Ann. Temp. Range: 29 C° (52.2 F°)
Ann. Hr of Sunshine: 2762

(b)

(c)

(d)



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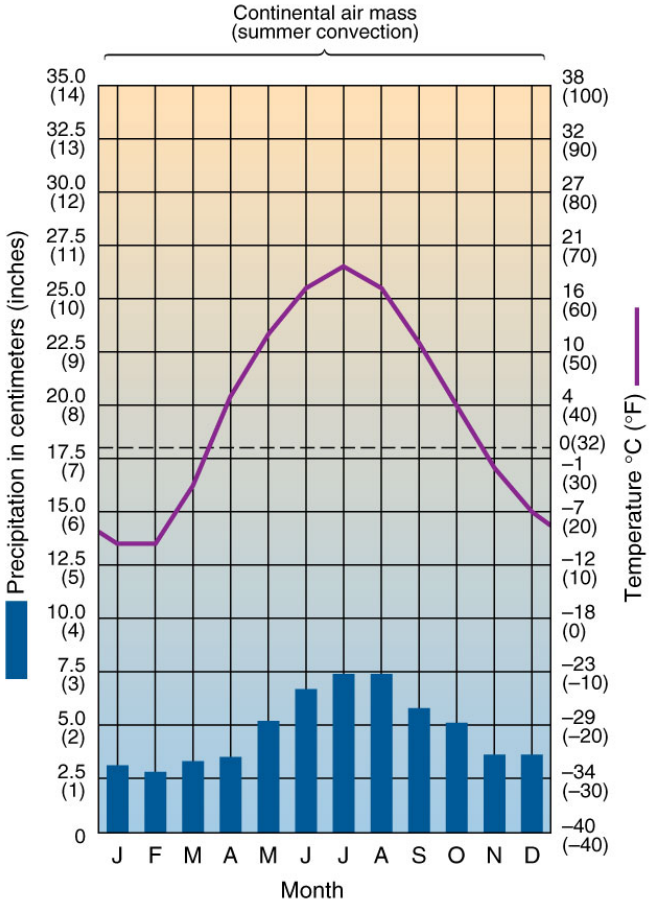
Humid Continental Mild-Summer Climates



Station: Moscow, Russia
Lat/long: 55°45′ N 37°34′ E
Avg. Ann. Temp.: 4°C (39.2°F)
Total Ann. Precip.: 57.5 cm (22.6 in.)

Elevation: 156 m (511.8 ft)
Population: 11,460,000
Ann. Temp. Range: 29 C° (52.2 F°)
Ann. Hr of Sunshine: 1597

(a)

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(b)

(c)

Figure 7.17

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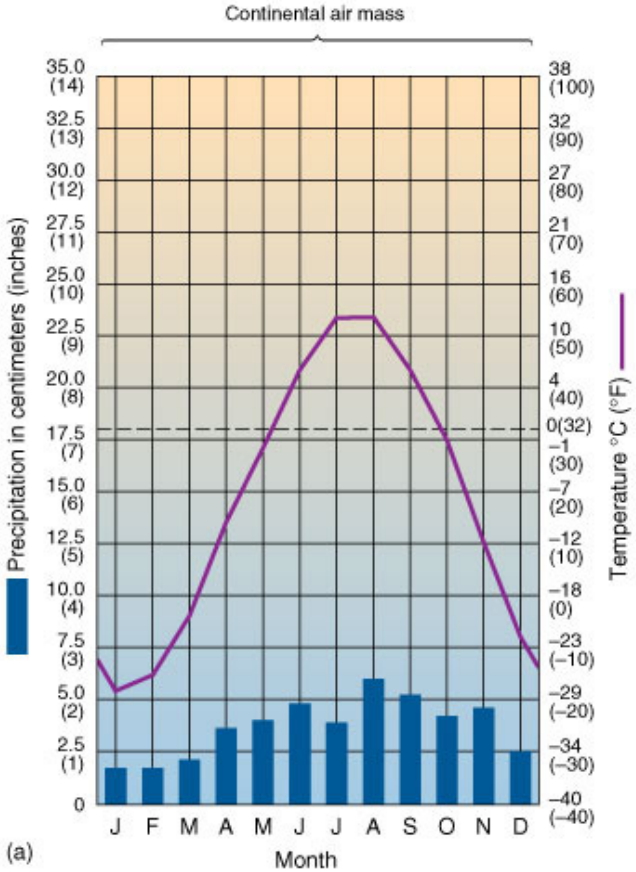
Subarctic Cool Summer Climates



Station: Churchill, Manitoba
Lat/long: 58°45′ N 94°04′ W
Avg. Ann. Temp.: −7°C (19.4°F)
Total Ann. Precip.: 44.3 cm (17.4 in.)
Elevation: 35 m (114.8 ft)
Population: 1400
Ann. Temp. Range: 40 C° (72 F°)
Ann. Hr of Sunshine: 1732

(b)

(c)

(d)

(e)

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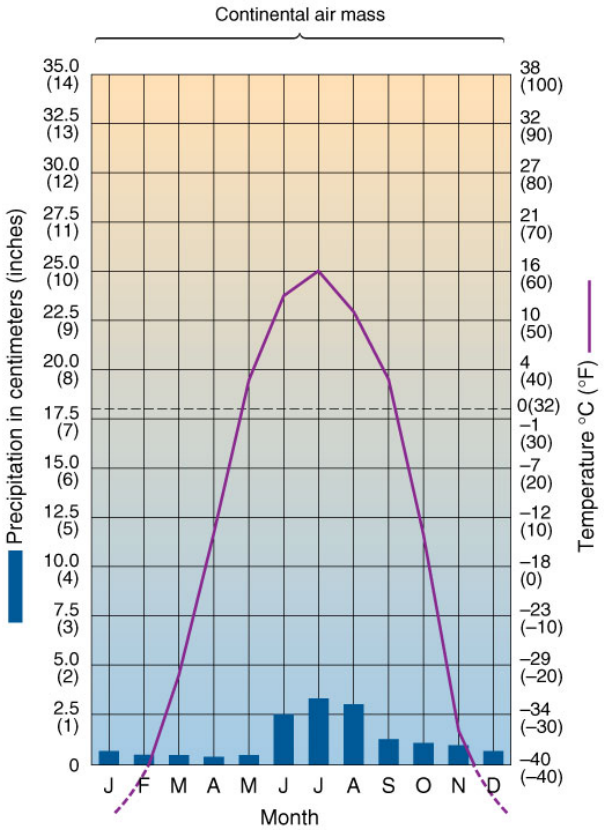
Extreme Subarctic Cold Winter



(b)

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Station: Verkhoyansk, Russia
Lat/long: 67°35′ N 133°27′ E
Avg. Ann. Temp.: –15°C (5°F)
Total Ann. Precip.: 15.5 cm (6.1 in.)
Elevation: 137 m (449.5 ft)
Population: 1500
Ann. Temp. Range: 63 C° (113.4 F°)

(a)

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Figure 7.19

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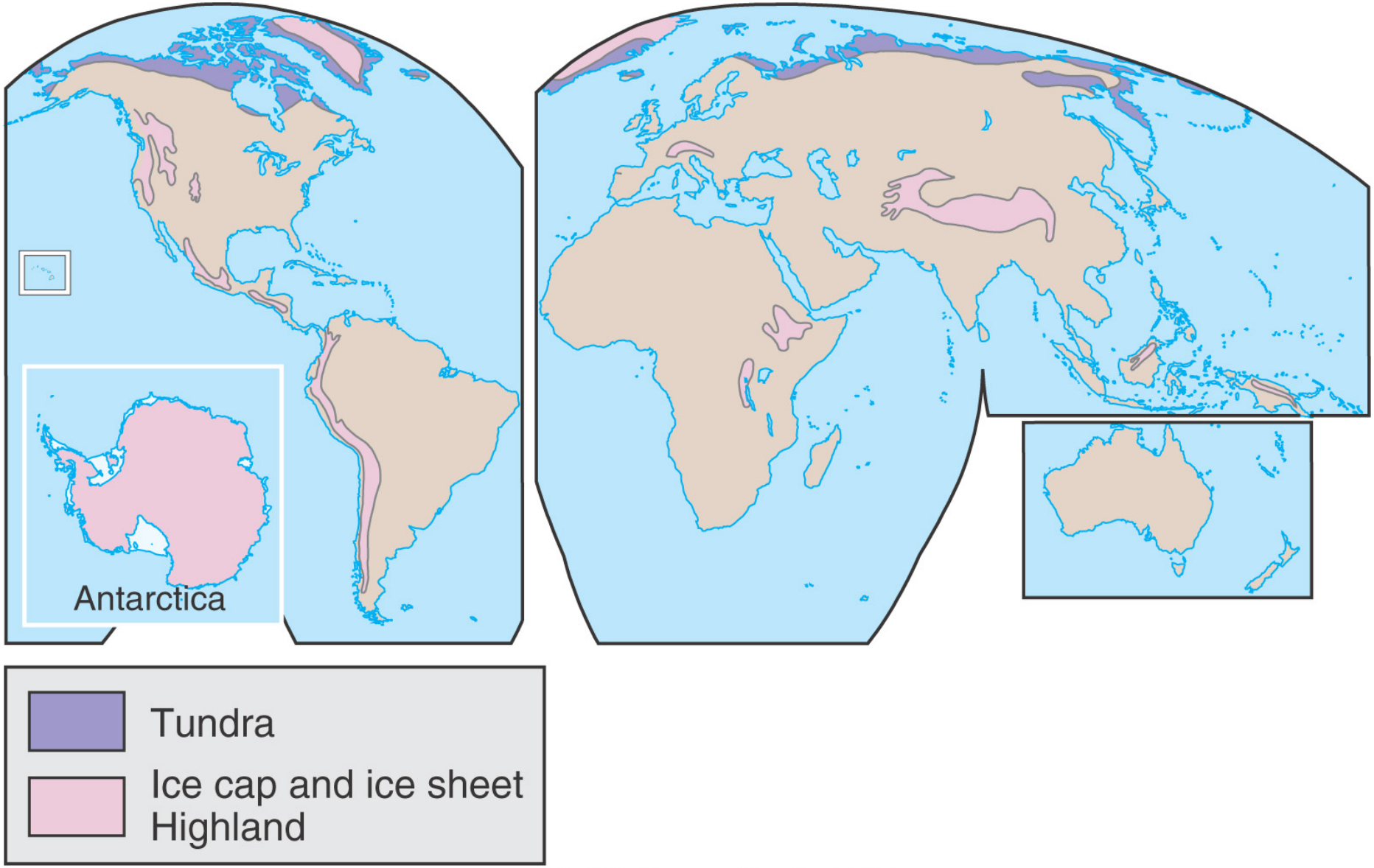
Köppen's Classification System

- Polar Climates - E
- Highland Climate - H
- Polar and Highland Climates
  - No true summer
  - Dominates the South Pole in the Antarctic, surrounded by the Southern ocean; North Pole region in the Arctic ocean, surrounded by the continents of North America and Eurasia
  - Daylight increases in summer until daylight becomes continuous
  - Average monthly temperatures always < $10^{o}C$

Polar and Highland Climates

- Tundra Climate (high latitude or elevation)
  - Land under continuous snow cover for 8 -10 months; warmest month above 0°C
  - Strictly a northern hemisphere occurrence
- Ice-Cap and Ice-Sheet Climate (perpetually frozen)
  - Most of Antarctica and Greenland fall within the ice-cap and ice-sheet climate, also the North Pole
  - All months averaging below freezing
  - Dominated by dry frigid air masses
- Polar Marine Climate (oceanic association, slight moderation of extreme cold)
  - More moderate than other polar climates in winter
  - Marine influences moderate annual temperature ranges

Polar and Highland Climates



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Köppen's Classification System

- *Dry, Desert Climates – B - (permanent moisture deficits)*
- Relative to temperature, the lower latitude deserts and steppes tend to be hotter with less seasonal change than the midlatitude deserts and steppes where mean annual temps. are below 18°C and freezing winter temps.
  - Arid deserts (tropical, subtropical, hot and midlatitude, cold)
    - Precipitation less than one-half the natural moisture demand
  - Semiarid steppes (tropical, subtropical, hot and midlatitude, cold)
    - Precipitation more than one-half the natural moisture demand

Köppen's Classification System

- Causal elements:
  - Dry, subsiding air in subtropical high-pressure system dominates
  - Midlatitude deserts and steppes form in the rain shadow of mountains, those to the lee of precipitation-intercepting mountains e.g. Lethbridge
  - Continental interiors (central Asia) are far from moisture bearing masses
  - Shifting subtropical high-pressure systems produce semi and steppe lands around the periphery of arid deserts

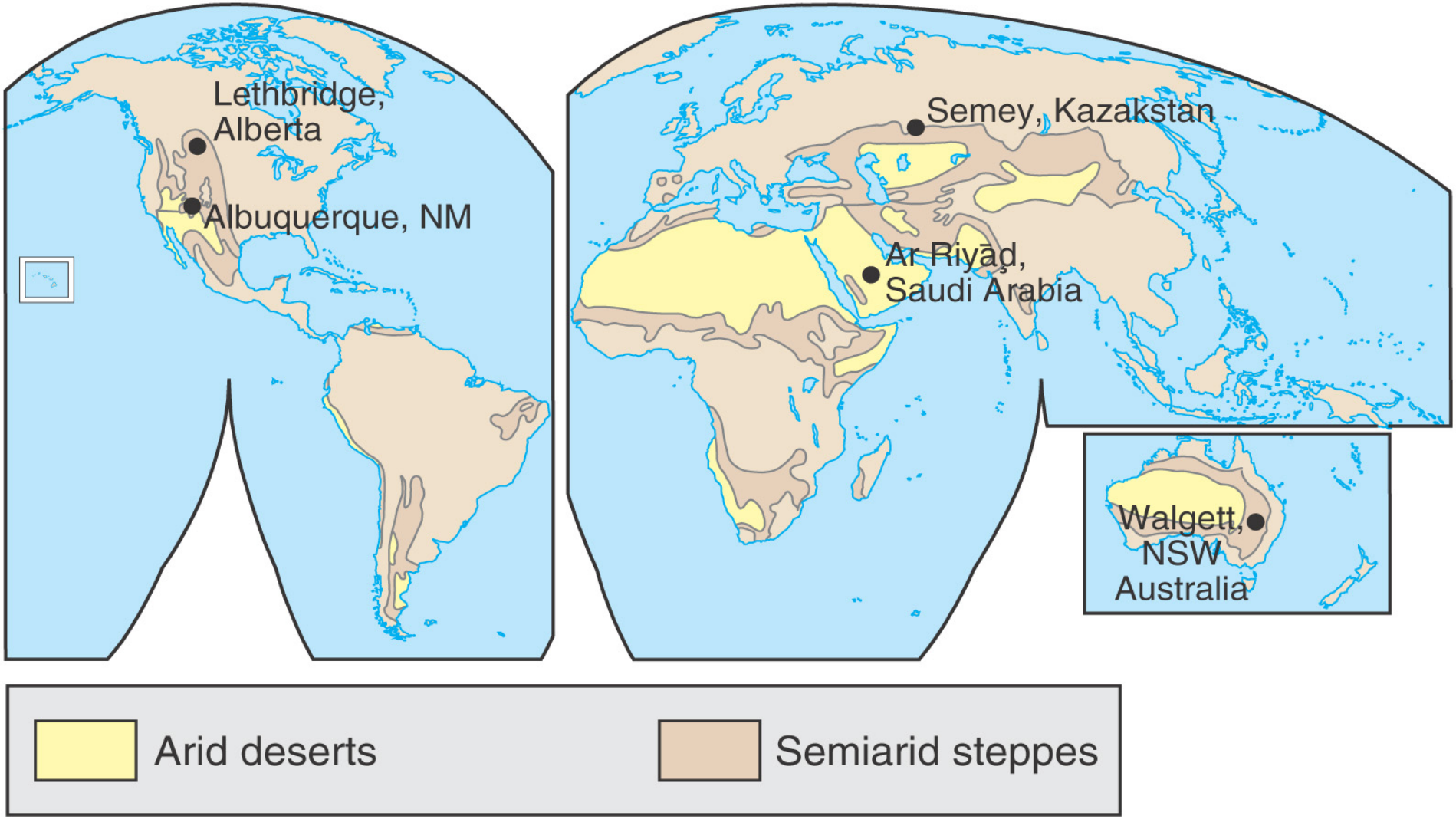
Arid and Semiarid Climates

- Desert Characteristics
  - Earth's dry climates extending between 15° -30°N & S latitude
  - Subtropical high-pressure cells predominate with subsiding, stable air and low relative humidity
- Tropical, Subtropical Hot Desert Climates
    - Generally concentrated on the western sides of continents as well as, Egypt, Somalia, and Saudi Arabia

Arid and Semiarid Climates

- Midlatitude Cold Desert Climates
  - Countries bordering southern Russia, The Gobi Desert, Mongolia in Asia, Patagonia Desert
  - Lower temperatures and lower natural moisture demand
- Tropical, Subtropical Hot Steppe Climates
  - Climates around the periphery of hot deserts like the Sahara, in Iran, Afghanistan, Turkistan, & Kazakstan
- Midlatitude Cold Steppe Climates
  - Occur poleward of 30° latitude and the midlatitude desert climates
  - Rainfall variable and undependable, ranging from 20 to 40 cm
  - Lethbridge

Arid and Semiarid Climates



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Desert Landscapes

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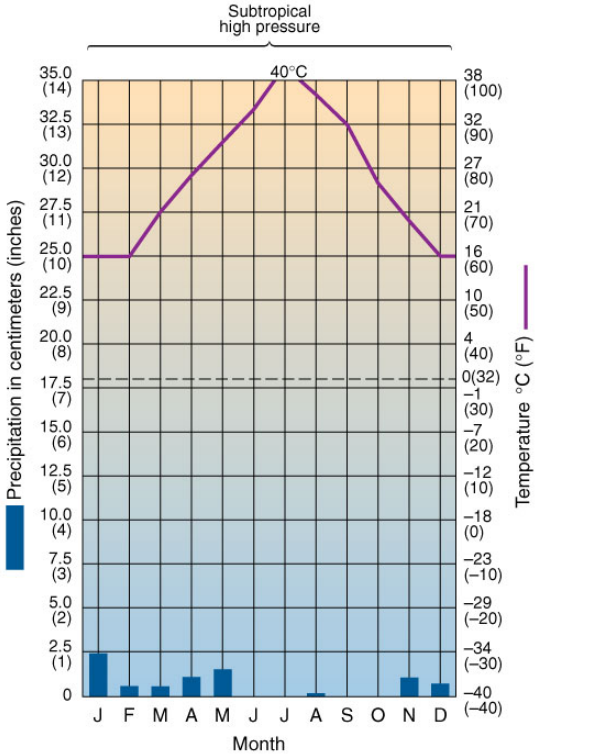
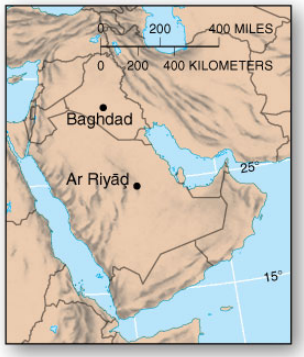
Figure 7.22

Tropical, Subtropical Hot Desert





(a)

Station: Ar Riyāḍ (Riyadh), Saudi Arabia
Lat/long: 24°42′ N 46°43′ E
Avg. Ann. Temp.: 26°C (78.8°F)
Total Ann. Precip.: 8.2 cm (3.2 in.)
Elevation: 609 m (1998 ft)
Population: 5,024,000
Ann. Temp. Range: 24 C° (43.2 F°)

(b)

(c)

Figure 7.23

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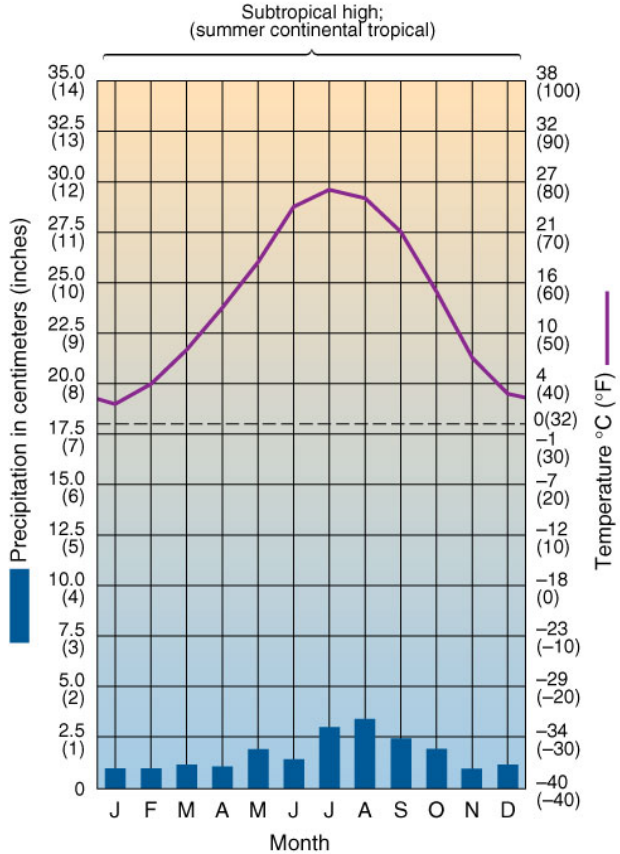
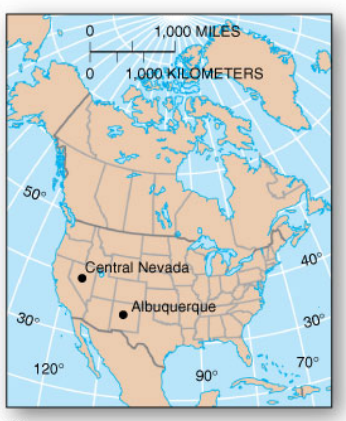
Midlatitude Cold Desert





(a)

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Station: Albuquerque, New Mexico
Lat/long: 35°03′ N 106°37′ W
Avg. Ann. Temp.: 14°C (57.2°F)
Total Ann. Precip.: 20.7 cm (8.1 in.)
Elevation: 1620 m (5315 ft)
Population: 449,000
Ann. Temp. Range: 24 C° (43.2 F°)
Ann. Hr of Sunshine: 3420

(b)

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Figure 7.24

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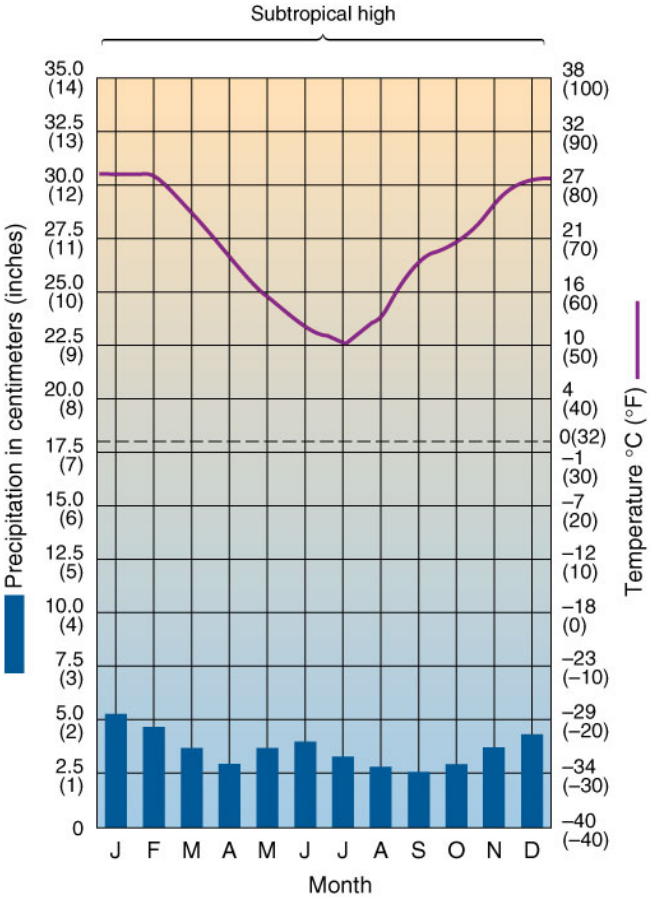
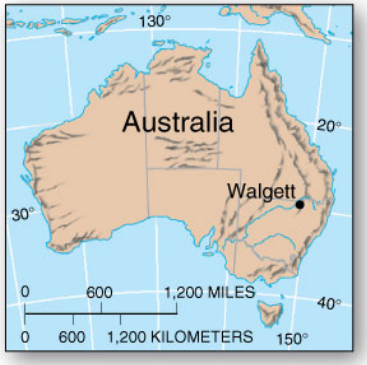
Tropical, Subtropical Hot Steppe





Station: Walgett, New South Wales, Australia
Lat/long: 30°0′ S 148°07′ E
Avg. Ann. Temp.: 20°C (68°F)
Total Ann. Precip.: 45.0 cm (17.7 in.)
Elevation: 133 m (436 ft)
Population: 2160
Ann. Temp. Range: 17 C° (31 F°)

(a)

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(b)

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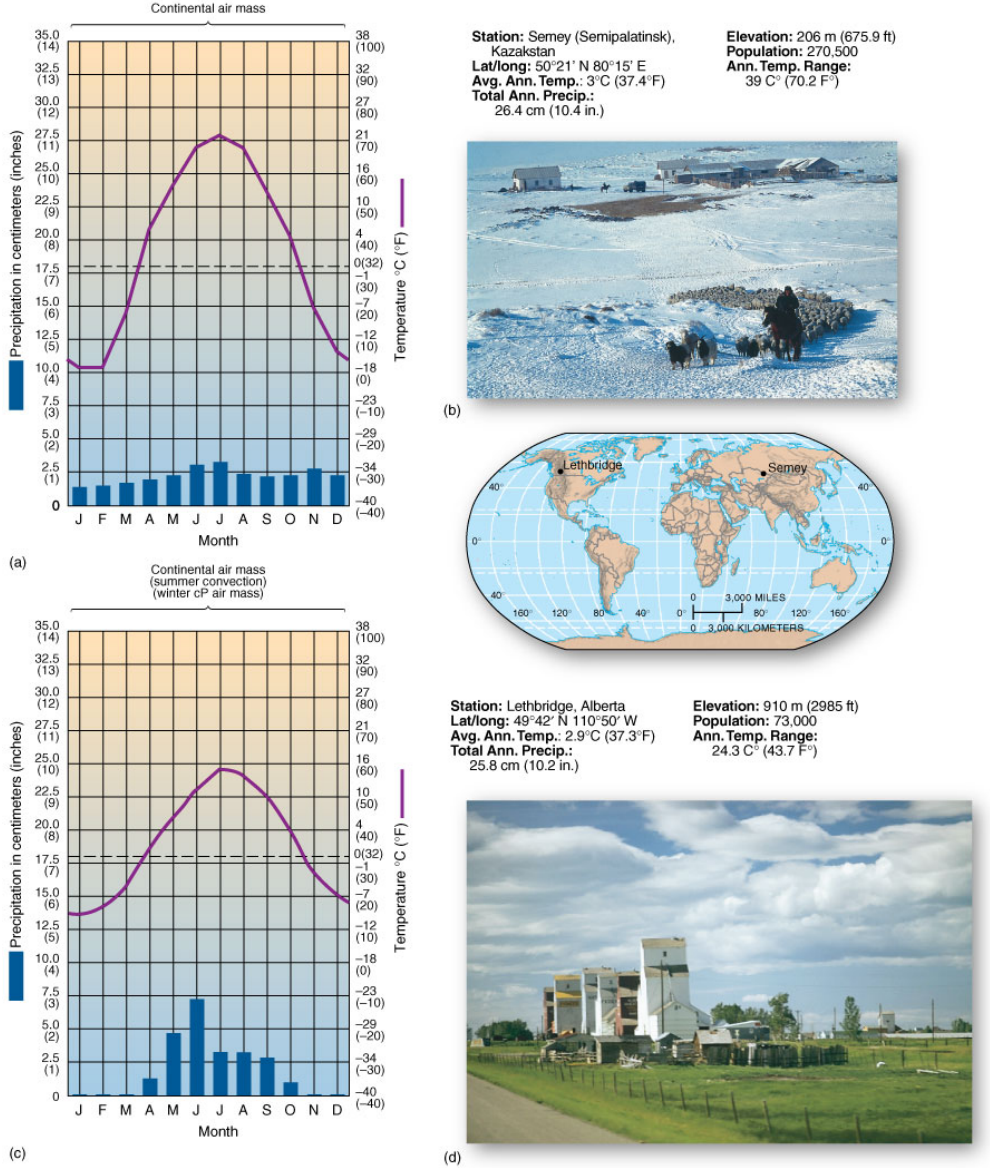
Midlatitude Cold Steppe



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Global Climate Change

- Global Warming
  - Greenhouse effect
    - Carbon dioxide, methane, nitrous oxide, CFCs, HFCs, PFCs
    - Accelerated warming trends over the last 50 y
      - » 20^{th}C warmest: avg. world temp. rose by ~0.6C
      - » Winter temp. in Arctic has risen
      - » Glaciers are thinning and retreating
- Climate Models and Future Temperatures
  - GCM - programs for the atmosphere, ocean, land surface, cryosphere, and biosphere; AOGCM

1000 Years of Temperature and CO_2

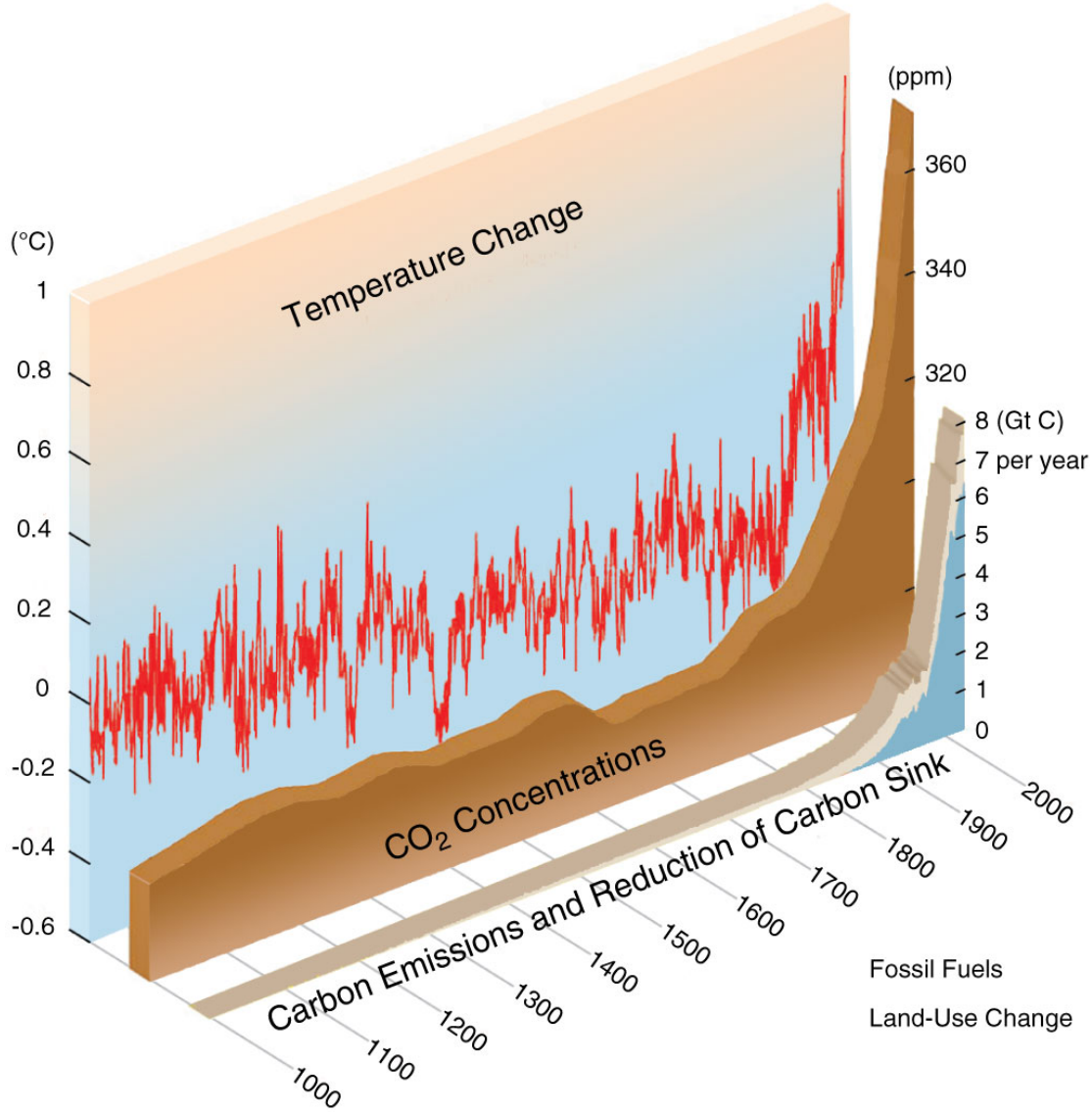

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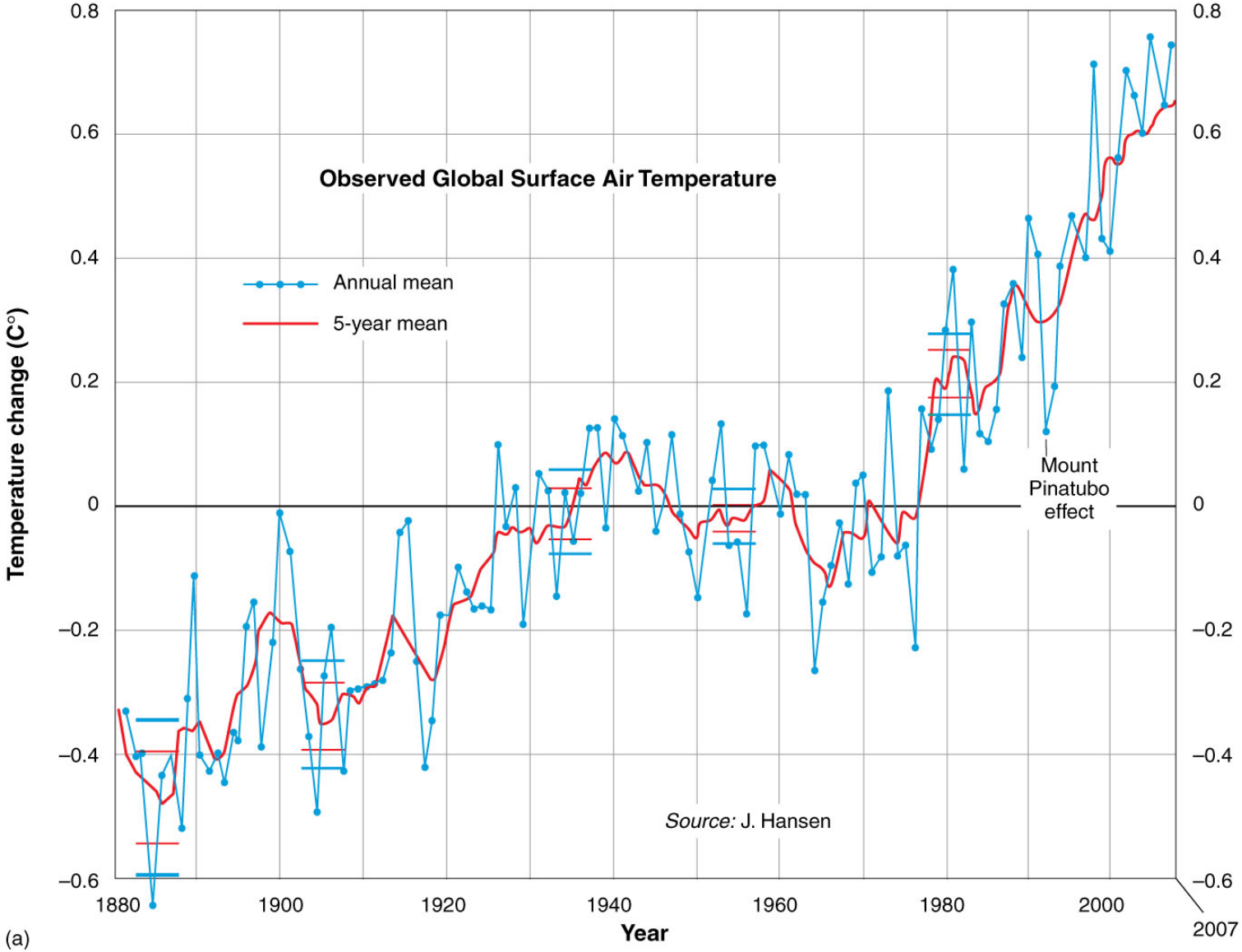
Figure 7.27

Global Temperatures



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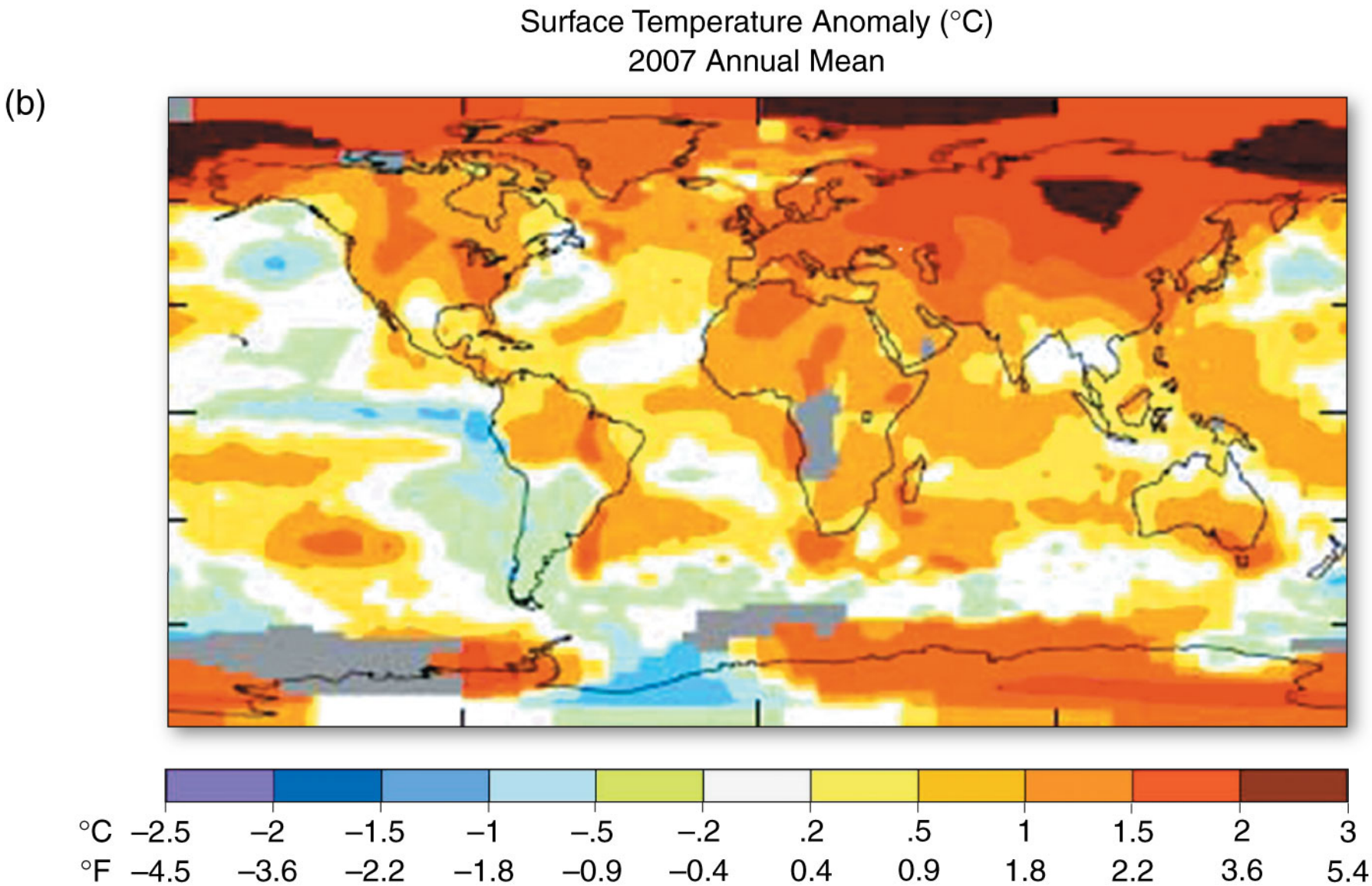
Temperature Anomalies



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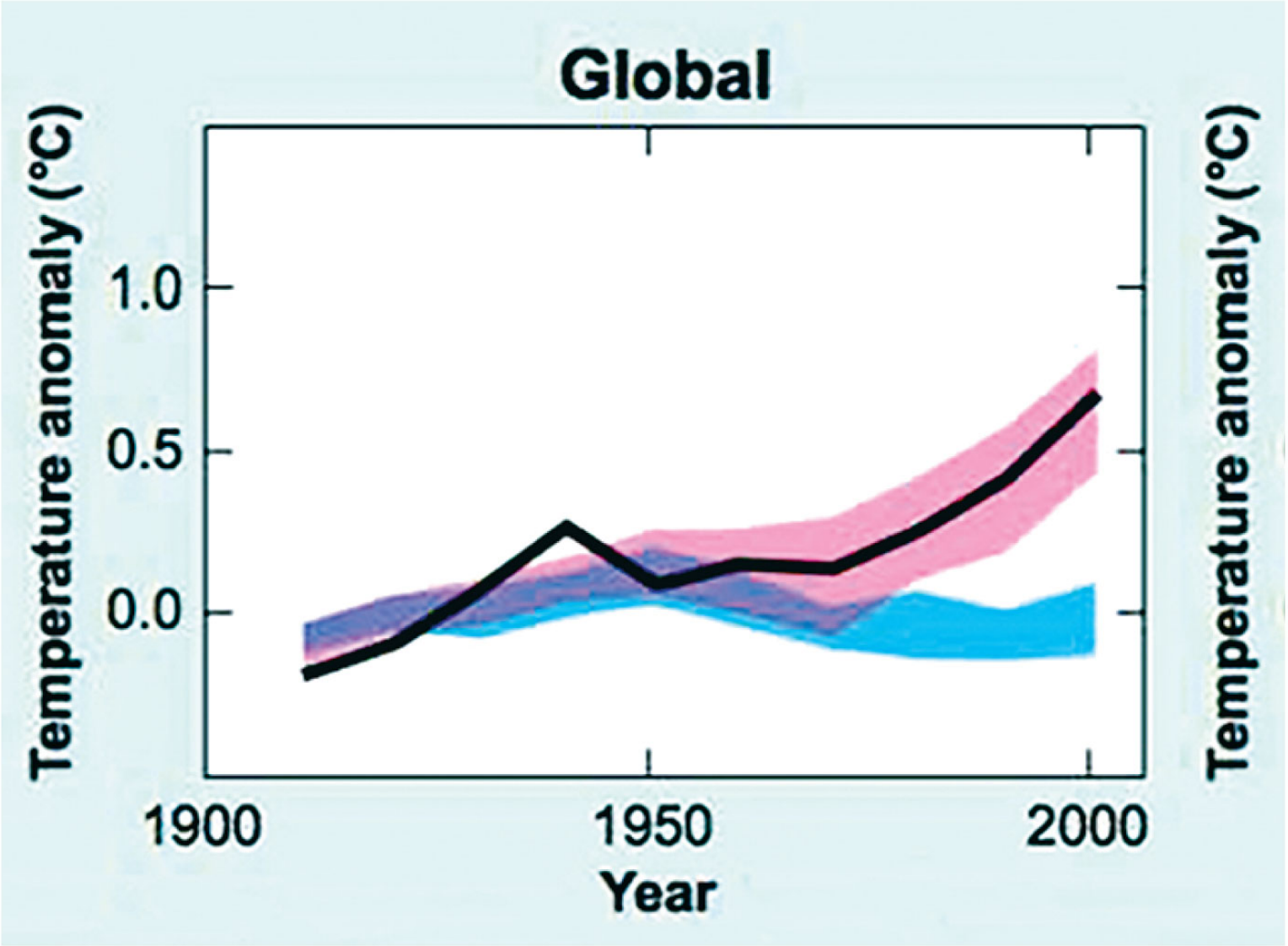
Anthropogenic vs. Natural Forcing



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10,000 Years of CO_2 Levels

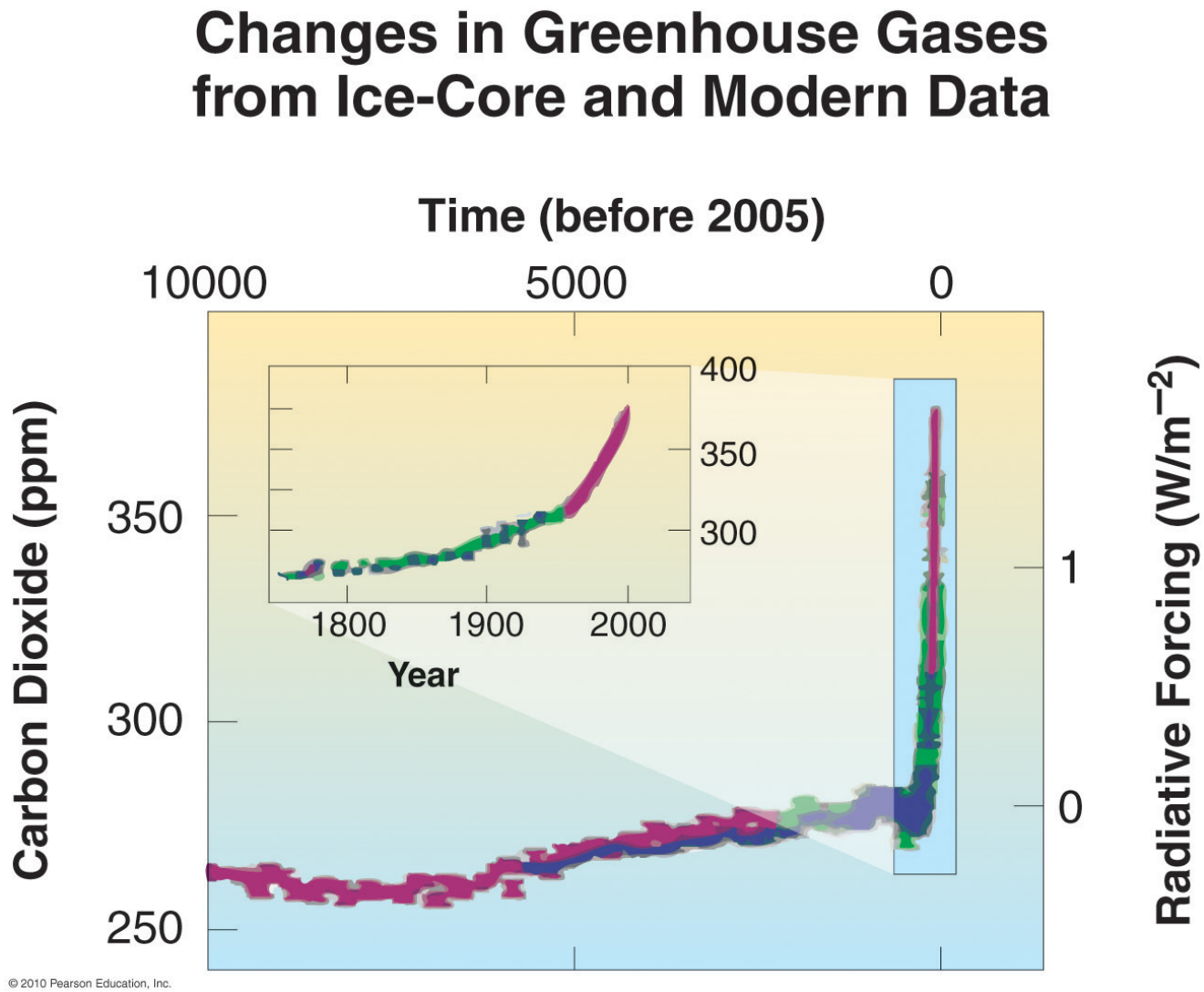
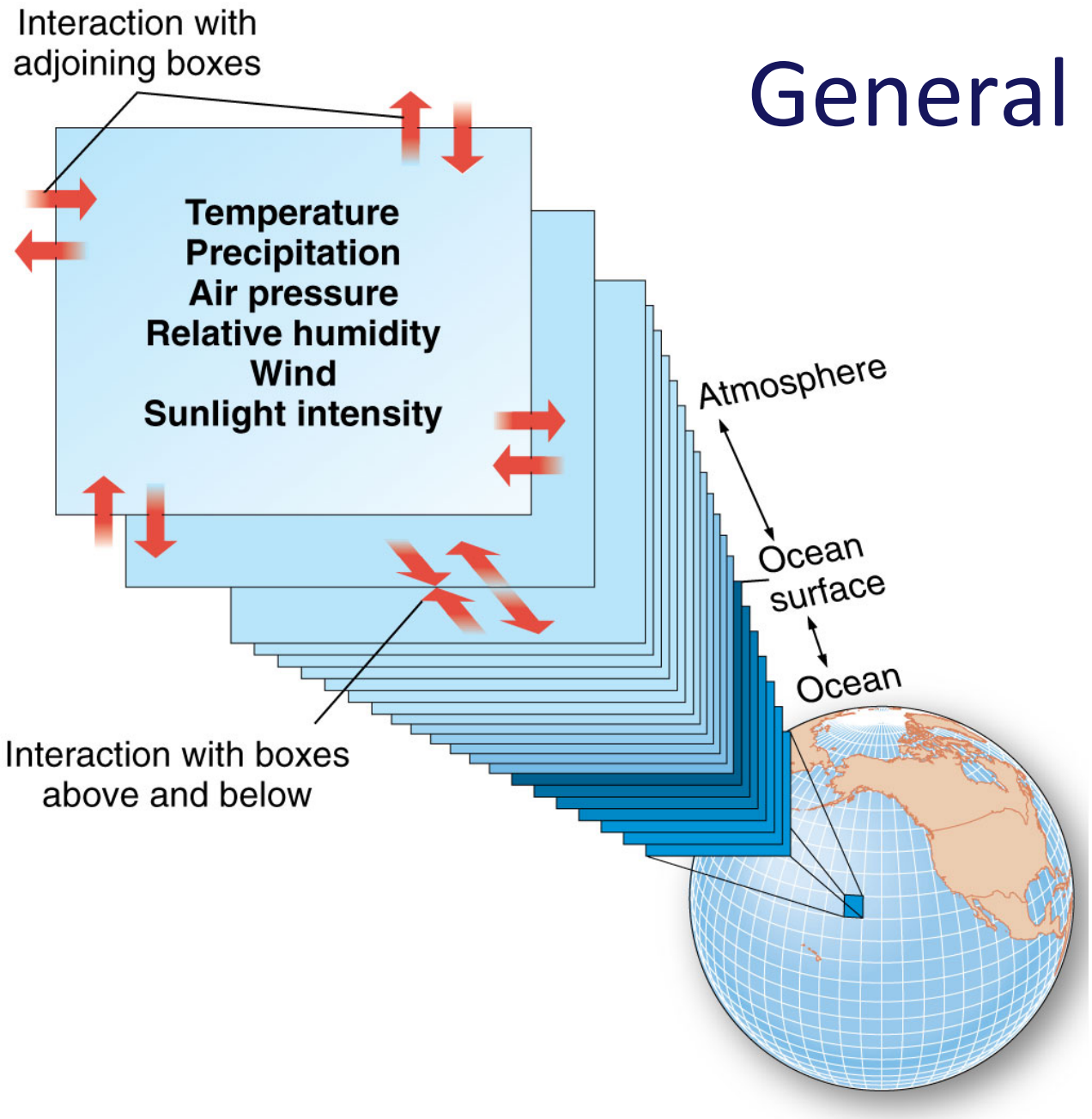


Figure 7.30

Global Warming

- Consequences of Global Warming
  - Tropospheric warming and stratospheric cooling
  - Widespread changes in extreme temperatures
  - Average global ocean temperatures increase to depths of 3000m and the ocean absorbed > 80% of climate system heating – contributes to sea-level rise
  - Increased intensity of tropical cyclones; worldwide there are more category 3, 4, 5 tropical storms than in the previous record
  - Mountain glaciers and snow cover declined on average in both hemispheres
  - Average atmospheric water vapor content has increased over land and ocean as well as in the upper atmosphere
  - Flow speed accelerated for some Greenland and Antarctic outlet glaciers
  - Changes in precipitation and evaporation over the oceans and the melting of ice are refreshing the seas at higher latitudes
  - Crop patterns, as well as, natural habitats of plants and animals, will shift to maintain preferred temperatures
  - Biosphere models predict that a global average of 30% of the present forest cover will undergo major species redistribution – greatest at high latitudes and least in the tropics

General Circulation Model



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Model Scenarios for Surface Heating

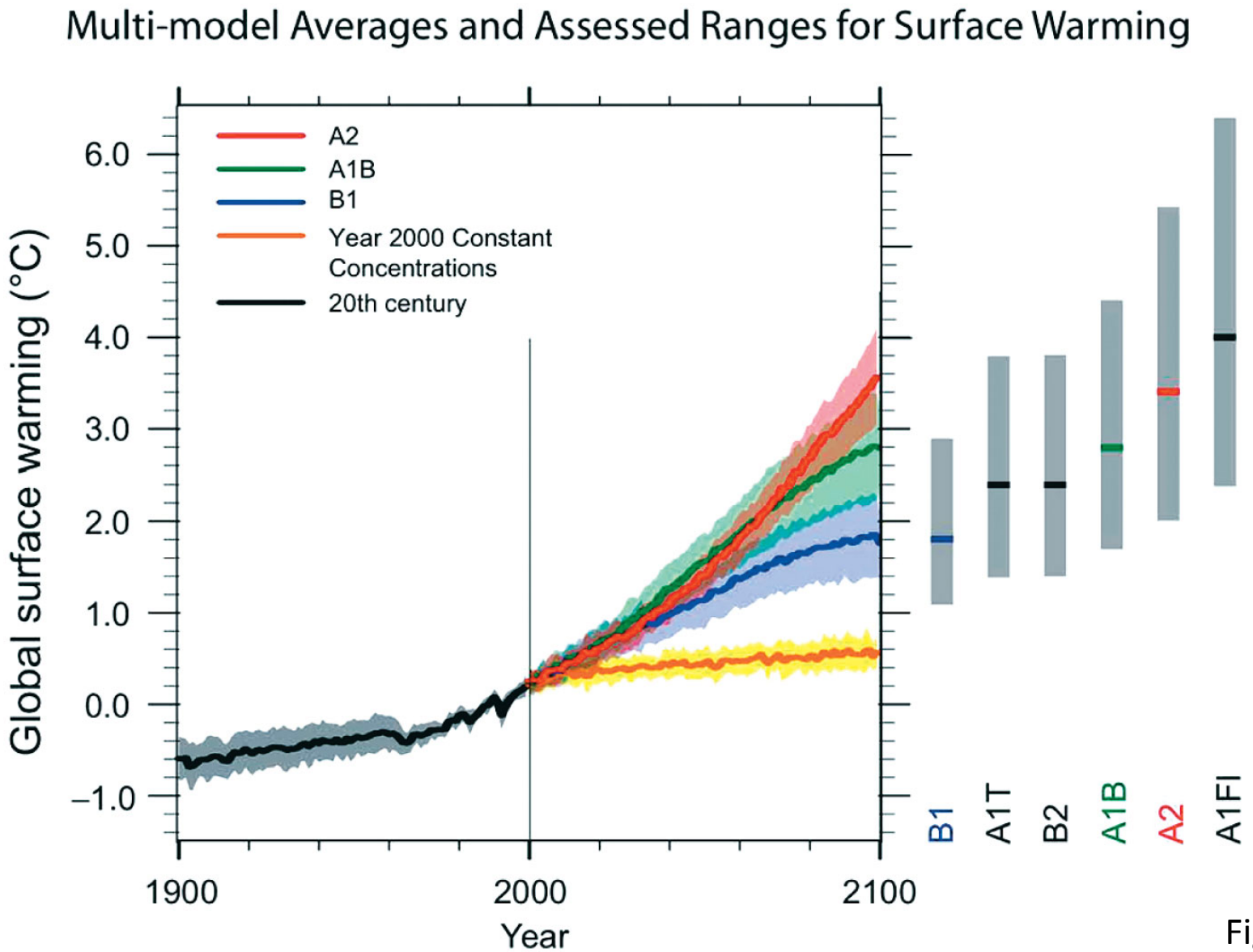

Figure 7.32

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End of lecture

Next lecture Chapter 8